Chapter 5
Academic Research and Development

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Highlights

Financial Resources for Academic R&D

In 2008, U.S. academic institutions spent $52 billion on R&D, and the higher education sector continues to account for the majority of basic research performed in the United States.

- Academic performers are estimated to account for 55% of U.S. basic research ($69 billion), 31% of total (basic plus applied) research ($157 billion), and 13% of all R&D ($395 billion) estimated to have been conducted in the United States in 2008.
- Higher education's share of total U.S. research expenditures increased by 11 percentage points between 1982 and 2002 (from 24% to 35%), but has since declined to an estimated 31% in 2008.

Support from the federal government decreased in recent years with no funding growth for 3 straight years.

- The federal government provided 60% ($31.2 billion) of funding for academic R&D expenditures in 2008. In inflation-adjusted dollars, this represents a 0.2% increase from FY 2007 and follows decreases of 1.6% in FY 2007 and 0.2% in FY 2006.
- According to the federal agencies providing the funding, total federal obligations for academic R&D peaked in 2004 at $22.1 billion (in constant 2000 dollars) and have since declined by almost 7% to an estimated $20.7 billion in FY 2009.

Higher education R&D funding from all nonfederal sources combined has grown steadily since FY 2004.

- The share of support provided by institutional funds increased steadily between 1972 (12%) and 1991 (19%) but since then has remained fairly stable at roughly one-fifth of total funding.
- After a 3-year decline between 2001 and 2004 (low of $2.1 billion), industry funding of academic R&D increased for the fourth year in a row, to $2.9 billion in 2008.

The distribution of academic R&D expenditures across the various broad S&E fields has remained relatively constant since 1990, with the life sciences receiving the most funding.

- In 2008, the life sciences continued to receive the largest share of investment in academic R&D, accounting for roughly 60% of all expenditures.
- Over the past two decades, the broad field of life sciences was the only field to experience any meaningful increase in its share of total academic R&D, rising more than 4 percentage points since 1998.

In 2008, about $1.9 billion was spent for academic research equipment. This represents a real increase of 1.0% from FY 2007, but a decline of more than 10% from the 2004 level.

- About 80% of FY 2008 equipment expenditures were concentrated in three fields: the life sciences (43%), engineering (23%), and the physical sciences (16%).
- After a period of steady growth between 2001 and 2004, equipment expenditures in the physical sciences, medical and biological sciences, and engineering have all declined since 2005.

Academic R&D Infrastructure

Research-performing colleges and universities continued to expand their physical resources for conducting research. However, while cyberinfrastructure capabilities continued to expand significantly, the expansion of traditional "bricks and mortar" infrastructure slowed.

- A large majority of institutions now have connections to high-speed networks; 25% of institutions have more than one connection.
- By FY 2007, 74% of all institutions had internal network distribution speeds of at least 1 gigabit.
- For the first time in 20 years, almost half of all S&E fields experienced a decline in their research space.

Doctoral Scientists and Engineers in Academia

The size of the doctoral academic S&E workforce reached an estimated 272,800 in 2006 but grew more slowly than the number of S&E doctorate holders in other employment sectors from 1973 to 2006. Full-time faculty positions, although still the predominant type of employment, increased more slowly than postdoc and other full- and part-time positions, especially at research universities.

- The share of all S&E doctorate holders employed in academia dropped from 55% in 1973 to 45% in 1991 and has remained at about that level through 2006.
- Among S&E doctorate holders in academia, full-time faculty declined continually from 88% in the early 1970s to 72% in 2006.
- Postdocs and others in full-time nonfaculty positions constitute an increasing percentage of academic S&E employment, having grown from 10% in 1973 to 22% in 2006. This change was especially pronounced in the 1990s.
- The share of part-time positions was roughly 2% to 4% from 1973 through 1999, but has risen since then to 6% in 2006.

The number of academic S&E doctorate holders reporting research as their primary or secondary work activity showed greater growth from 1973 to 2006 than the number reporting teaching as their primary or secondary activity.

- The number of researchers grew 2.5% per year (from 82,300 to 183,700) between 1973 and 2006, and the number of teachers grew 1.7% per year (from 94,900 to 163,300).
- About two-thirds of doctoral scientists and engineers employed in academic institutions are engaged in research as either a primary or secondary work activity.

Life scientists accounted for more than one-third of academic doctorate holders reporting research as a primary or secondary work activity in 2006. Life scientists also accounted for most of the growth in academic researchers.

- The number of academic researchers in the physical sciences and mathematics grew more slowly, at average annual growth rates of 1.1% and 1.6%, respectively, from 1973 to 2006. Growth rates for academic researchers in all fields were greatest in the 1980s.
- The number of full-time faculty in the life sciences has risen, but the percentage of full-time faculty in the life sciences who are tenured or on the tenure track has declined because the number of tenured and tenure-track life scientists has remained fairly stable since the late 1980s.

The demographic composition of academic researchers changed substantially between 1973 and 2006.

- Women increased from 6% to 29% of full-time doctoral S&E research faculty from 1973 to 2006.
- Underrepresented minorities (blacks, Hispanics, and American Indians/Alaska Natives) increased from about 2% to about 8% of full-time doctoral S&E research faculty.
- The Asian/Pacific Islander share of full-time doctoral S&E research faculty increased substantially, from 4% to 13%.
- The share of whites among full-time doctoral S&E research faculty fell from 92% to 79% during the period.

In most fields, the percentage of full-time doctoral S&E faculty with federal support for their work was about the same in 2006 as it was in the late 1980s.

- A little less than half (46%) of full-time doctoral S&E faculty received federal support in both 1987 and in 2006.
- Among full-time faculty, recent doctorate recipients were less likely to receive federal support than their more established colleagues.

Outputs of Academic S&E Research: Articles and Patents

S&E article output worldwide grew at an average annual rate of 2.5% between 1995 and 2007. The U.S. growth rate was much lower, at 0.7%.

- The United States accounted for 28% of the world total S&E articles in 2007, down from 34% in 1995. The share of the European Union also declined, from 35% in 1995 to 32% in 2007.
- In Asia, average annual growth rates were high—for example, 17% in China and 14% in South Korea. As a result, in 2007 China moved past the United Kingdom, Germany, and Japan to rank as the world's 2nd-largest producer, up from 5th place in 2005 and 14th place in 1995.

The research portfolios of the top article-producing countries, as indicated by publication of S&E articles, varied widely. China, Japan, and eight other Asian countries (the "Asia-8") emphasized the physical sciences more than the United States and the European Union.

- In 2007, S&E research articles in chemistry and physics accounted for just under one-half of China's total article production, 36% of Japan's, and 37% of the Asia-8's. These two fields accounted for 17% of the total for the United States and 25% of the total for the European Union.
- Articles in the life sciences (biological, medical, agricultural, and related sciences) accounted for 57% of all U.S. S&E articles, compared with 49% for the European Union, 25% for China, 45% for Japan, and 34% for the Asia-8.
- Country research portfolios also differed in their emphasis on engineering, with the Asian countries more heavily concentrated in this broad field (China at 16%, Japan at 11%, and the Asia-8 at 19%) than the U.S. or the European Union (7%–8%).

S&E research articles continue to indicate increasing collaboration across institutions in the United States and internationally.

- Coauthored articles grew from 40% of the world's total S&E articles in 1988 to 64% in 2008. Coauthored articles listing only authors from different institutions in the same country increased from 32% of all articles in 1988 to 42% in 2008. Articles listing authors from institutions in more than one country grew from 8% to 22% over the same period.
- Within-sector coauthorship increased in all U.S. sectors, growing, for example, from 38% of academic S&E article output in 1998 to 45% in 2008. Cross-sector coauthorship increased generally, mainly due to an increase of 7–10 percentage points in each nonacademic sector's coauthor-

ship with academia. U.S. sector coauthorship with foreign authors grew in all sectors by 7–10 percentage points.

The U.S. share of world article output and article citations has declined but not the influence of U.S. research articles, as indicated by the percentage of U.S. articles that are among the most highly cited worldwide.

- Between 1998 and 2008, the U.S. share of world articles declined from 34% in 1998 to 29% in 2008, while its share of total citations in S&E articles declined from 47% to 38%. Over the same period, China's share of publications increased from 2% to 6%, and its share of citations from 1% to 4%.
- The percentage of U.S.-authored S&E articles receiving the highest number of citations—an indicator of research quality and high impact on subsequent research—has changed little. Between 1998 and 2008, the U.S. index of highly cited articles declined from 1.83 to 1.78 and remained well above the expected index value of 1. Indexes of the European Union, China, Japan, and the Asia-8 all increased but remained below 1.

Indicators of academic patenting are mixed. U.S. Patent and Trademark Office (USPTO) data show that patent grants to U.S. universities declined to about 3,000 in 2008. Other indicators relating to academic patenting suggest increasing activity.

- According to USPTO data, patent grants to universities and colleges increased sharply from 1988 to about 1999, when they peaked at just under 3,700 patents, and then fell to about 3,000 in 2008. Three technology areas have dominated these patent awards (chemistry, biotechnology, and pharmaceuticals), accounting for 45% of the total patents awarded to U.S. universities in 2008.
- Data from another source show that invention disclosures filed with university technology management offices grew from 13,700 in 2003 to 17,700 in 2007 and that patent applications filed by reporting universities and colleges increased from 7,200 in 2003 to almost 11,000 in 2007.

Introduction

America's academic institutions play a pivotal role in the U.S. system for conducting R&D and fostering innovation. They conduct the bulk (55%) of U.S. basic research and in the process train the nation's new researchers. U.S. universities have also become active participants in turning new research-based knowledge into innovative products and processes and in broader regional economic development activities. This chapter analyzes available data bearing on these points. (For the key output of trained personnel, see chapter 2.)

Chapter Overview

U.S. universities and colleges carry out the majority of basic research activity (55%) and a substantial portion of all R&D in the United States. The federal government has been and continues to be the major financial supporter of academic R&D, providing more than 60% of the funding in 2007. Other major funding sources are the institutions themselves, industry, and state and local government.

Over the past two decades, the shares of funding allocated to the various S&E fields[1] have changed, with the share going to medical sciences growing substantially and the share going to physical sciences and engineering declining.

Academic R&D is conducted largely by doctoral scientists and engineers. Over time, universities and colleges have relied less on full-time tenure-track faculty and more on postdocs and other nonfaculty to conduct research; in addition, a steady percentage of full-time graduate students has been supported by research assistantships. The demographic composition of academic researchers is changing, with increasing numbers of women and minorities, especially among the younger age groups, and increasing numbers of foreign-born scientists and engineers.

A measure of research output, the number of U.S. S&E articles published in the world's leading S&E journals, recently began to increase after remaining flat for almost a decade, concurrent with strong growth in the European Union and several Asian countries. However, the U.S. share of the world's S&E article output has declined since the early 1970s. The U.S. share of the world's influential—i.e., most highly cited—articles has declined, though U.S. scientific publications remain highly influential relative to those of other countries. Article output by the academic sector, which publishes most U.S. research articles, mirrored the overall U.S. trend, even as research inputs (specifically, academic R&D expenditures and research personnel) continued to increase.

Both domestic and international R&D collaboration have increased significantly over the past two decades. U.S. scientists and engineers in all sectors collaborated extensively with colleagues in other U.S. sectors and abroad. The results of academic research increasingly extend beyond articles to patents, which are an indicator of academic institutions' efforts to protect the intellectual property derived from their inventions, and to technology transfer, university-industry collaboration, and other related activities such as revenue-generating licenses and formation of startup companies that emanate from their institution.

This chapter addresses key aspects of the academic R&D enterprise, including the level, field allocation, and institutional distribution of academic R&D funds; the state of research equipment and facilities at academic institutions; trends in the number and composition of the academic S&E doctoral labor force; and indicators of research outputs.

Chapter Organization

The first section of this chapter discusses the role of academia within the national R&D enterprise. This discussion is followed by an examination of trends in the financial resources provided for academic R&D, including identification of key funders and allocations of funds across both academic institutions and S&E fields. Because the federal government has been the primary source of support for academic R&D for more than half a century, the importance of selected agencies to both overall support and support for individual fields is explored in some detail. This section also presents data on changes in the distribution of funds among academic institutions, on the number of academic institutions that receive federal R&D support, and on equipment.

The next section examines the status of the physical infrastructure necessary to conduct university research activities. Data are presented on both the traditional research infrastructure such as research space, and on infrastructure resulting from technological changes such as networking.

The third section discusses trends in employment of academic doctoral scientists and engineers, especially those engaged in research. Major trends examined include numbers and characteristics of academic doctoral scientists and engineers, the types of positions they hold, their research activities, and the federal support for their research. The section also examines reported collaboration among researchers.

The chapter concludes with an analysis of trends in two types of research outputs: S&E articles, as measured by data from a set of journals covered by the Science Citation Index (SCI) and the Social Sciences Citation Index (SSCI), and patents issued to U.S. universities. (A third major output of academic R&D, educated and trained personnel, is discussed in chapter 2 and in the preceding section of this chapter.) This section looks specifically at the volume of research (article counts), collaboration in the conduct of research (joint authorship), use in subsequent scientific activity (citation patterns), and use beyond science (citations to the literature that are found in patents). It concludes with a discussion of academic patenting and some returns to academic institutions from their patents and licenses.

Financial Resources for Academic R&D

Academic R&D is a significant part of the national R&D enterprise.[2] Academic scientists and engineers conduct the bulk of the nation's basic research, about one-third of its

Data Sources for Financial Resources for Academic R&D

The data used to describe financial and infrastructure resources for academic R&D are derived from three National Science Foundation (NSF) surveys. These surveys use similar but not always identical definitions, and the nature of the respondents also differs across the surveys. The three main surveys are as follows:

- Survey of Federal Funds for Research and Development
- Survey of Research and Development Expenditures at Universities and Colleges
- Survey of Science and Engineering Research Facilities

The first survey collects data from federal agencies, whereas the last two collect data from universities and colleges.

Data presented in the first part of this section, "Academic R&D Within the National R&D Enterprise," are derived from the NSF series National Patterns of R&D Resources, which sums results from several NSF surveys of the various sectors of the U.S. economy (for example, universities, businesses, and the federal government) so that the components of the overall R&D effort are placed in a national context. These data are reported on a calendar-year basis, and the data for 2008 are preliminary. Since 1998, the series has also attempted to eliminate double counting in the academic sector by subtracting current fund expenditures for separately budgeted S&E R&D that are passed through to other institutions via subcontracts and similar collaborative research arrangements.

Data in subsequent portions of the section derive from the Survey of Research and Development Expenditures at Universities and Colleges (Academic R&D Expenditures Survey). They are reported on an academic fiscal-year basis (e.g., FY 2008 covers July 2007 to June 2008 for most institutions) and do not net out the funds passed through to other institutions; therefore, they differ from those reported earlier. Data on major funding sources, funding by institution type, distribution of R&D funds across academic institutions, and expenditures by field and funding source are also derived from this survey.

The data on "Top Agency Supporters" and "Agency Support by Character of Work" in the "Federal Support of Higher Education R&D" section come from NSF's Survey of Federal Funds for Research and Development. This survey collects data on R&D obligations for each federal fiscal year (e.g., FY 2008 covers October 2007 through September 2008) from 30 federal agencies. Data for FY 2008–09 are preliminary estimates. The amounts reported for FY 2008–09 are based on administration budget proposals and do not necessarily represent actual appropriations. It should be noted that federal obligation data (e.g., $25.7 billion in federal FY 2008) do not match the federally funded expenditures data reported by academic institutions ($31.2 billion in academic FY 2008) for several reasons. First, the period covered by the two surveys is slightly different; second, there is necessarily a lag between the obligation date and the beginning of project expenditures and some awards span multiple years; and third, some of the expenditures data double count federal R&D awards that are reported both by the primary institution receiving the funds and again by an academic subrecipient to whom funds are passed through (about $1.5 billion in FY 2008).

Data on research equipment are taken from the Survey of Research and Development Expenditures at Universities and Colleges. Data on research facilities and cyberinfrastructure are taken from the Survey of Science and Engineering Research Facilities and are also reported by academic fiscal year. The population for this survey is a subset of the population for the Academic R&D Expenditures Survey and includes all institutions reporting $1 million or more in current fund expenditures for R&D. The Facilities survey was broadened starting in FY 2003 to include data on computing and networking capacity. Although terms are defined specifically in each survey, in general, *facilities expenditures* are classified as capital projects, are fixed items such as buildings, often cost millions of dollars, and are not included in R&D expenditures as reported here. *Research equipment,* however, is purchased with *current funds* (those in the yearly operating budget for ongoing activities) and is included within R&D expenditures. Because the categories are not mutually exclusive, some large instrument systems could be classified as either facilities or equipment. Generally, academic institutions account separately for capital projects and current fund expenditures.

Redesign of the Survey of R&D Expenditures at Universities and Colleges

The Survey of Research and Development Expenditures at Universities and Colleges has been conducted annually since 1972. In 2007, NSF began an intensive 3-year effort to evaluate and redesign the survey. The goals of the redesign were to (1) update the survey instrument to reflect current accounting principles in order to obtain more valid and reliable measurements of the amount of academic R&D spending in the United States, (2) expand the current survey items to collect the additional detail most often requested by data users, and (3) evaluate the feasibility of expanding the scope of data collected beyond that of R&D expenditures.

As part of the redesign effort, NSF held data user workshops and expert panel meetings, worked with accounting and survey methodology experts, and visited more than 40 institutions to receive input on possible changes to the survey. A pilot test of the redesigned survey was administered to 40 institutions during the fall of 2009, and full implementation of the redesigned survey is planned for the fall of 2010.

The new survey, now titled the "Higher Education R&D Survey," will continue to capture core information on R&D expenditures by sources of funding and field. In addition, it will include the following data:

- Total R&D expenditures funded by nonprofit institutions (previously included under "Other sources")
- Total R&D expenditures funded from all types of foreign sources
- Total R&D expanded to include R&D expenditures in both S&E and non-S&E fields as well as clinical trial expenditures
- Detail by field (both S&E and non-S&E) for R&D expenditures from each source of funding (federal, state/local, institution, industry, nonprofit, and other)
- Total R&D expenditures from projects within university interdisciplinary research centers (test metric on interdisciplinary R&D)
- Total R&D expenditures by direct cost categories (salaries, software, equipment, etc.)
- Counts of proposals submitted during the fiscal year
- Counts and dollar amounts of R&D awards during the fiscal year, with a breakout of stimulus awards

In addition to these changes, NSF has also been working with data users and experts to explore the feasibility of collecting systematic data on both R&D personnel and intellectual property and commercialization within universities and colleges. It is expected that additional questions on these topics will be added to the Higher Education R&D Survey in future years.

total (basic plus applied) research, and 13% of its total R&D. To carry out world-class research and advance the scientific knowledge base, U.S. academic researchers require adequate and stable financial resources and the research facilities and instrumentation that facilitate high-quality work. For a discussion of the sources of the data used in this section, see sidebar, "Data Sources for Financial Resources for Academic R&D."

Academic R&D Within the National R&D Enterprise

Universities and colleges play an important role in the nation's overall R&D effort, especially by contributing to the generation of new knowledge through basic research.[3] Since 1998, basic research performed within institutions of higher education has accounted for more than half of the basic research performed in the United States.

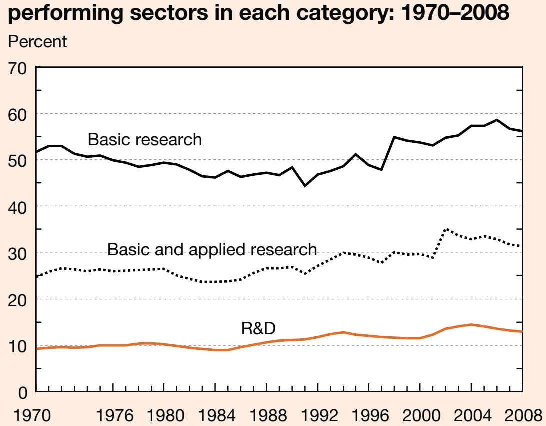
In 2008, U.S. universities and colleges spent $52 billion ($42 billion in constant 2000 dollars) on R&D. Higher education's prominence as an R&D performer increased slightly during the past three decades, rising from about 10% of all R&D performed in the United States in the early 1970s to an estimated 13% in 2008 (figure 5-1). For a comparison with other countries, see "International R&D Comparisons" in chapter 4.

Academic R&D involves mostly basic and applied research and little development activity.[4] In 2008, an estimated 96% of academic R&D expenditures went for research (76% for basic and 21% for applied) and 4% for development (appendix table 5-1). Universities and colleges accounted for an estimated 31% of the U.S. basic and applied research total in 2008, down from a high of 35% in 2002 but still above the levels prevalent until then (figure 5-1). Higher education's share of total U.S. research expenditures had previously increased by 11 percentage points between 1982 and 2002. In terms of basic research alone, the higher education sector is the country's largest performer, currently accounting for an estimated 55% of the national total.

Federal Support of Higher Education R&D

Higher education R&D relies heavily on federal support, along with a variety of other funding sources. The federal government has consistently contributed the majority of the funds (figure 5-2).[5] It accounted for about 60% of the $51.9 billion of R&D funds expended by universities and colleges in FY 2008 (appendix table 5-2).[6] In current dollars, federally funded

Figure 5-1
Academic R&D, basic and applied research, and basic research as share of U.S. total from all performing sectors in each category: 1970–2008

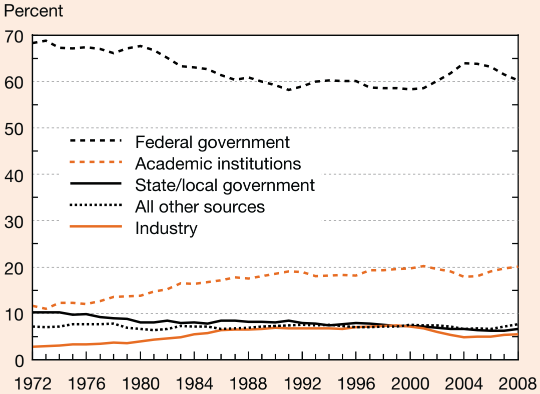


NOTES: Preliminary data for 2008. Because of changes in estimation procedures, character of work data before FY 1998 not comparable with later years. Data based on annual reports by performers.

SOURCE: National Science Foundation, Division of Science Resources Statistics, National Patterns of R&D Resources (annual series). See appendix table 5-1. Also see appendix tables 4-3, 4-7, 4-11, and 4-15 for data underlying percentages.

Science and Engineering Indicators 2010

Figure 5-2
Sources of academic R&D funding: 1972–2008



SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Research and Development Expenditures at Universities and Colleges: FY 2008. See appendix table 5-2.

Science and Engineering Indicators 2010

academic R&D expenditures rose 2.5% between FY 2007 and FY 2008 to $31.2 billion. After adjustment for inflation, this represents a 0.2% increase from FY 2007 and follows 2 years of slight declines in constant dollars since FY 2005.

Another look at recent trends is provided by federal agency-reported inflation-adjusted obligations for academic R&D—funds going to academic institutions in a given fiscal year, to be spent over the current and succeeding years. In constant 2000 dollars, federal academic R&D obligations peaked in FY 2004 at $22.1 billion and have since declined by almost 7% to an estimated $20.7 billion in FY 2009 (appendix table 5-3). Constant dollar federal R&D obligations had grown more than 10% each year between FY 1998 and FY 2001, largely reflecting a commitment to double the R&D budget of the National Institutes of Health (NIH) over 5 years. Consequently, between 1998 and 2004, NIH's share of federal academic R&D funding increased from 57% to 63%.

The American Recovery and Reinvestment Act, signed into law by President Obama on February 17, 2009, provides an additional $18.3 billion in appropriations for federal R&D and R&D facilities and equipment in FY 2009. (See "Federal R&D" in chapter 4.)[7]

The federal government's overall contribution is the combined result of numerous discrete funding decisions made by several R&D-supporting agencies with differing missions and purposes, which in turn affect research priorities in the academic sector. Most of the federal R&D funding to the higher education sector is allocated through competitive peer review (see sidebar, "Congressional Earmarks").

Examining and documenting the funding patterns of the key funding agencies is important to understanding both their roles and that of the federal government overall. For a discussion of a major federal program with the objective of improving the geographical distribution of federal obligations for academic R&D, see sidebar, "EPSCoR: The Experimental Program to Stimulate Competitive Research."

Congressional Earmarks

Academic earmarking is the congressional practice of providing federal funds to educational institutions for facilities or projects without merit-based peer review. Obtaining exact figures for either the amount of funds or the number of projects earmarked for universities and colleges, overall or for research, is difficult. There is no accepted definition of an earmark, and funding legislation is often obscure in its description of the earmarked projects. Broad estimates using a consistent approach in compiling these data are as follows.

Academic earmarks stood at an estimated $2.3 billion in FY 2008 (Brainard and Hermes 2008), a 15% increase over an estimated $2.0 billion reported last in FY 2003 in the *Chronicle of Higher Education* (Brainard and Borrego 2003). Approximately two-thirds ($1.6 billion) of the FY 2008 funds and $1.4 billion of FY 2003 funds were for R&D projects, R&D equipment, or construction or renovation of R&D laboratories.

Top Agency Supporters

Six agencies are responsible for most of the federal obligations for higher education R&D, providing an estimated 97% of the $25.7 billion obligated in FY 2009 (appendix table 5-3).[8] NIH was by far the largest funder, providing an estimated 65% of total federal academic R&D obligations in FY 2009. The National Science Foundation (NSF) provided an additional 15%, the Department of Defense (DOD) 8%, the Department of Energy (DOE) 4%, the National Aeronautics and Space Administration (NASA) 2%, and the U.S. Department of Agriculture (USDA) 2%.

Agency Support by Character of Work

More than 56% of federal obligations from FY 2007 through FY 2009 funded basic research projects (appendix table 5-4). The two agencies funding the majority of academic basic research were NIH and NSF. More than one-third of federal obligations for academic R&D from 2007 through 2009 funded applied research, with NIH providing the vast majority of funds in that category as well. About 5% of R&D obligations went toward development during 2007–09. DOD and NASA were responsible for more than 80% of the small amount of federal academic R&D funds spent on development.

Other Sources of Funding

In contrast to the recent trend in federal R&D funding, higher education R&D funding from nonfederal sources has grown steadily since FY 2004, and grew by 8% (6% in inflation-adjusted terms) between 2007 and 2008 (figure 5-3).

- **Institutional funds.** In FY 2008, institutional funds from universities and colleges constituted the second largest source of funding for academic R&D, accounting for

EPSCoR: The Experimental Program to Stimulate Competitive Research

EPSCoR, the Experimental Program to Stimulate Competitive Research, originated as a response to a number of stated federal objectives. Section 3(e) of the National Science Foundation Act of 1950, as amended, states that "it shall be an objective of the Foundation to strengthen research and education in the sciences and engineering, including independent research by individuals, throughout the United States, and to avoid undue concentration of such research and education."

In 1978, Congress authorized NSF to implement EPSCoR in response to broad public concerns about the extent of geographical concentration of federal funding for R&D. Eligibility for EPSCoR participation was limited to those jurisdictions that historically had received lesser amounts of federal R&D funding and had demonstrated a commitment to develop their research bases and to improve the quality of S&E research conducted at their universities and colleges.

The success of the NSF EPSCoR programs during the 1980s subsequently prompted the creation of EPSCoR and EPSCoR-like programs in six other federal agencies: the Departments of Energy, Defense, and Agriculture; the National Aeronautics and Space Administration; the National Institutes of Health; and the Environmental Protection Agency. In FY 1992, the EPSCoR Interagency Coordinating Committee (EICC) was established by the federal agencies with EPSCoR or EPSCoR-like programs. The major objectives of the EICC focused on improving coordination among and between the federal agencies in implementing EPSCoR and EPSCoR- like programs consistent with the policies of the participating agencies.

EPSCoR seeks to increase the R&D competitiveness of an eligible state through the development and utilization of the science and technology (S&T) resources residing in its colleges and universities. It strives to achieve this objective by (1) stimulating sustainable S&T infrastructure improvements at the state and institutional levels that significantly increase the ability of EPSCoR researchers to compete for federal and private sector R&D funding and (2) accelerating the movement of EPSCoR researchers and institutions into the mainstream of federal and private sector R&D support.

In FY 2008, the seven EICC agencies invested a total of $419 million on EPSCoR and EPSCoR-like programs, up from approximately $97 million in 1999 (see table 5-A). The Environmental Protection Agency discontinued issuing separate EPSCoR program solicitations in FY 2006.

Table 5-A
EPSCoR and EPSCoR-like program budgets, by agency: FY 1998–2008
(Millions of dollars)

Agency	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
All agencies	74.1	96.7	139.8	225.3	288.9	358.0	353.3	367.4	367.1	363.1	418.9
DOD	18.0	19.0	24.0	18.7	15.7	15.7	8.4	11.4	11.5	9.5	17.0
DOE	6.8	6.8	6.8	7.7	7.7	11.7	7.7	7.6	7.3	7.3	14.7
EPA	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.4	0.0	0.0	0.0
NASA	5.0	10.0	10.0	10.0	10.0	10.0	10.0	12.0	12.5	12.8	15.5
NIH	5.0	10.0	40.0	100.0	160.0	210.0	214.0	222.0	220.0	218.0	223.6
NSF	36.8	48.4	51.3	74.8	79.3	88.8	93.7	93.4	97.8	101.5	120.0
USDA	NA	NA	5.2	11.6	13.7	19.3	17.0	18.6	18.0	14.0	28.1

NA = not available

DOD = Department of Defense; DOE = Department of Energy; EPA = Environmental Protection Agency; EPSCoR = Experimental Program to Stimulate Competitive Research; NASA = National Aeronautics and Space Administration; NIH = National Institutes of Health; NSF = National Science Foundation; USDA = U.S. Department of Agriculture

NOTE: EPA discontinued issuing separate EPSCoR program solicitations in FY 2006.

SOURCE: Data provided by agency EPSCoR representatives; collected by NSF Office of Integrative Activities, Office of EPSCoR, May 2009.

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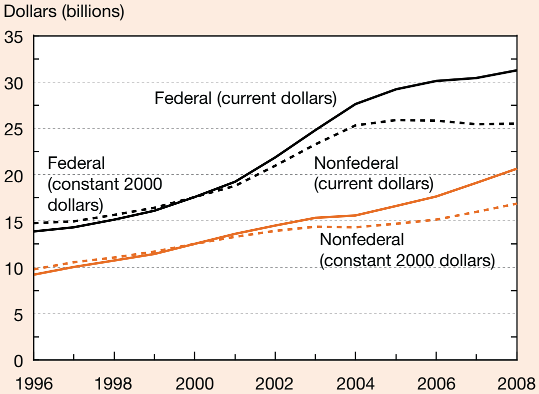
20% ($10.4 billion) of the total (appendix table 5-2). Institutional funds encompass (1) institutionally financed research expenditures and (2) unrecovered indirect costs and cost sharing. They exclude departmental research, a more informal type of research that is usually coupled with instructional activities in departmental budget accounts and thus does not meet the Office of Management and Budget definition of organized research. The share of support represented by institutional funds increased steadily from 12% in 1972 to 19% in 1991 and has since remained at roughly that level. Funds for institutionally financed R&D may derive from general-purpose state or local government appropriations; general-purpose awards from industry, foundations, or other outside sources; endowment income; and gifts. Universities may also use income from patents, licenses, or patient care revenues to support R&D. (See section "Patent-Related Activities and Income" later in this chapter for a discussion of patent and licensing income.)

Figure 5-3
Federal and nonfederal academic R&D expenditures: 1996–2008



NOTE: See appendix table 4-1 for gross domestic product implicit price deflators used to convert current dollars to constant 2000 dollars.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Research and Development Expenditures at Universities and Colleges: FY 2008. See appendix table 5-2.

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- **State and local government funds.** State and local governments provided 7% ($3.4 billion) of higher education R&D funding in FY 2008. Even though their absolute funding total continues to rise annually, the nonfederal government share has declined since its peak of 10.2% in the early 1970s. However, these figures are likely to understate the actual contribution of state and local governments to academic R&D, particularly for public institutions, because they only reflect funds that these governments directly target to academic R&D activities.[9] They exclude any general-purpose state or local government appropriations that academic institutions designate and use to fund separately budgeted research or pay for unrecovered indirect costs; such funds are categorized as *institutional funds*.[10] (See chapter 8, "State Indicators," for some indicators of academic R&D by state.)
- **Industry funds.** Industrial support accounts for the smallest share of academic R&D funding (6%), and support of academia has never been a major component of industry-funded R&D. After a 3-year decline between 2001 and 2004, industry funding of academic R&D increased for the fourth year in a row, to $2.9 billion in FY 2008. (See appendix table 4-5 for time-series data on industry-reported R&D funding.)
- **Other sources of funds.** In FY 2008, other sources of support accounted for 8% ($4.0 billion) of academic R&D funding, a level that has stayed about the same since 1972. This category of funds includes but is not limited to grants and contracts for R&D from nonprofit organizations and voluntary health agencies and all other sources not included in the other categories.

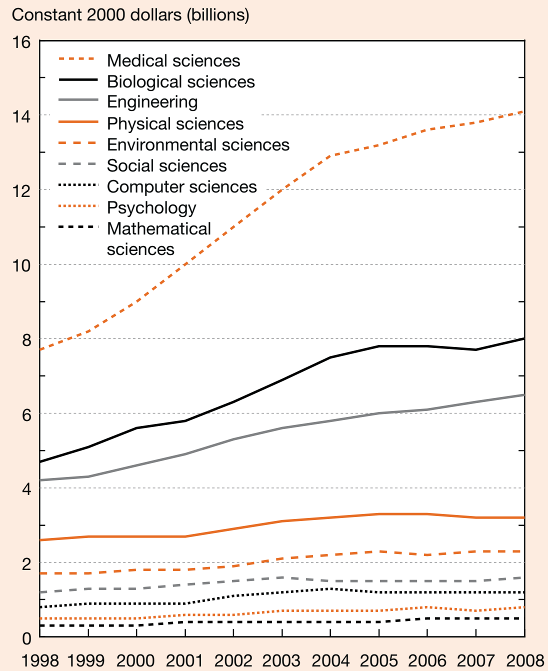
Expenditures by Field and Funding Source

Investment in academic R&D historically has been concentrated in a few individual S&E fields. The life sciences have for decades accounted for more than half of all academic R&D expenditures. In FY 2008, they accounted for approximately 60% of both the federal and nonfederal totals (appendix table 5-5). Within the life sciences, the medical sciences accounted for 33% of all academic R&D expenditures and the biological sciences accounted for another 19% (appendix table 5-5).[11]

Between 1998 and 2008, R&D expenditures in the medical sciences almost doubled, from $7.7 billion to $14.1 billion in constant 2000 dollars (figure 5-4), changing the distribution of academic R&D expenditures across the various broad S&E fields. The life sciences gained 4 percentage points over the period, driven by a 4-percentage-point rise in the share of medical sciences, from 29% to 33% of the total (appendix table 5-6). The physical sciences lost 2 percentage points, from 10% to 8% of the total. Figure 5-5 shows share gains and losses in both the 1990–2000 and 2000–08 periods.

Of the $31.2 billion in academic R&D expenditures funded by the federal government, R&D projects in the life sciences accounted for $18.7 billion (60%) in FY 2008 (appendix table 5-7).

Figure 5-4
Academic R&D expenditures, by field: 1998–2008



NOTE: See appendix table 4-1 for gross domestic product implicit price deflators used to convert current dollars to constant 2000 dollars.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Research and Development Expenditures at Universities and Colleges: FY 2008. See appendix table 5-6.

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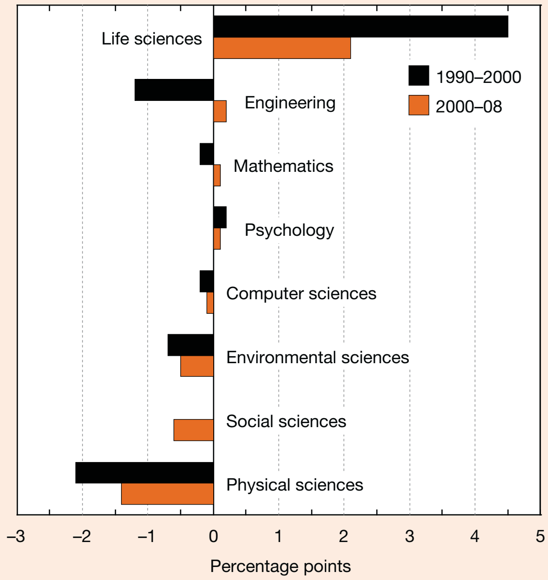
Figure 5-5
Changes in share of academic R&D in selected S&E fields: 1990–2000 and 2000–08



NOTE: Fields ranked by change in share during 2000–08, in descending order.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Research and Development Expenditures at Universities and Colleges: FY 2008. See appendix table 5-6.

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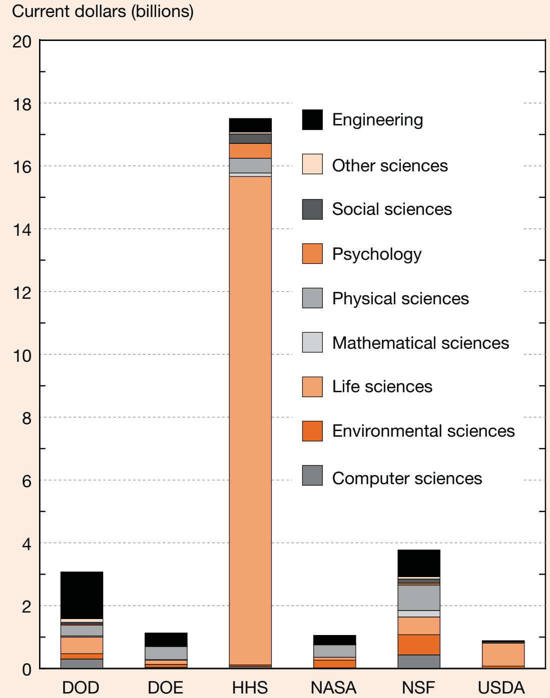
Figure 5-6
Federally financed academic R&D expenditures, by agency and field: FY 2008



DOD = Department of Defense; DOE = Department of Energy; HHS = Department of Health and Human Services; NASA = National Aeronautics and Space Administration; NSF = National Science Foundation; USDA = U.S. Department of Agriculture.

NOTE: Some institutions unable to provide complete agency data by field. Data not adjusted for nonresponse.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Research and Development Expenditures at Universities and Colleges, FY 2008. See appendix table 5-7.

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The Department of Health and Human Services (HHS), notably NIH, contributes the majority of this life science funding (83%). Although their share of total academic R&D funding is much smaller, DOD, DOE, NASA, and NSF have more diversified funding patterns (figure 5-6). In FY 2008, NSF was the lead federal funding agency for academic research in the physical sciences (29% of federally funded R&D expenditures); mathematical sciences (47%); computer sciences (42%); and environmental sciences (34%). DOD was the lead funding agency in engineering (32%).

The proportion of academic R&D expenditures funded by the federal government also varies significantly by field (appendix table 5-8). The field with the largest proportion of federal funding in FY 2008 was atmospheric sciences, at 80%, followed by physics (76%), mathematical sciences (72%), and aeronautical/astronautical engineering (72%). The fields with the smallest percentages of federal funding in FY 2008 were economics (32%), political science (37%), and agricultural sciences, which received less than 30% of their funds from federal sources.

Between 1975 and 1990, the federally financed proportion of R&D spending declined in *all* of the broad S&E fields (appendix table 5-8).[12] Since 1990, those declines have either stabilized or reversed, and the federal share reported in FY 2008 was higher than the 1990 share for all fields except mathematical sciences and physical sciences.

Non-S&E R&D Expenditures

Academic institutions spent a total of $2.2 billion on R&D in non-S&E fields in FY 2008 (table 5-1).[13] This represents an increase of 9% over the $2.1 billion spent in FY 2007.[14] This $2.2 billion is in addition to the $51.9 billion expended on S&E R&D. The largest amounts reported for R&D in non-S&E fields were for education ($880 million), business and management ($325 million), and humanities ($254 million). The federal government funds smaller proportions of R&D in non-S&E than in S&E fields: 37% of the $2.2 billion in non-S&E R&D in FY 2008.

Academic R&D by Institution

The previous sections examined R&D for the entire academic sector. This section looks at some of the differences across institution types.

Table 5-1
R&D expenditures in non-S&E fields at universities and colleges: FY 2007–08
(Millions of current dollars)

Field	2007 Total expenditures	2007 Federal expenditures	2008 Total expenditures	2008 Federal expenditures
All non-S&E fields	2,051	802	2,241	838
Business and management	273	52	325	65
Communication, journalism, and library science	90	31	89	29
Education	899	471	880	451
Humanities	241	60	254	63
Law	73	29	88	28
Social work	93	40	124	59
Visual and performing arts	46	4	59	4
Other non-S&E fields	335	116	422	139

NOTE: Detail may not add to total because some respondents reporting non-S&E R&D expenditures did not break out total and federal funds by non-S&E fields.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Research and Development Expenditures at Universities and Colleges, FY 2008.

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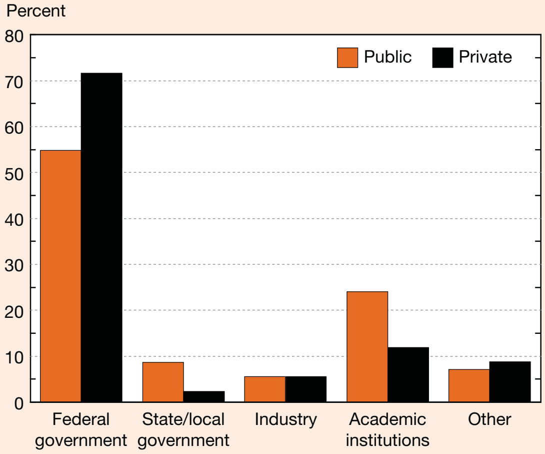
Funding for Public and Private Universities and Colleges

Public and private universities rely on the same major sources to fund their R&D projects, but the relative contribution of those sources differs substantially (figure 5-7; appendix table 5-9). In FY 2008, the federal government provided 72% of the R&D funds spent by private institutions, compared with 55% for public institutions. Conversely, public institutions received approximately 9% of their $35.3 billion in R&D expenditures from state and local governments, compared with 2% of private institutions' $16.6 billion.

Public academic institutions also supported a larger portion of their R&D from their own sources (24% versus 12% at private institutions). Their larger proportion of institutional R&D funds may reflect general-purpose state and local government funds that public institutions have directed toward R&D.[15] Private institutions in turn report a larger proportion of unrecovered indirect costs (53% of their institutional total in 2008, versus 42% for public institutions). For both types of institutions, these shares have declined over the past decade, from 64% to 53% for private institutions and from 46% to 42% for public institutions (figure 5-8).

Both public and private institutions received approximately 6% of their R&D support from industry in FY 2008.

Figure 5-7
Sources of academic R&D funding for public and private institutions: 2008



SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Research and Development Expenditures at Universities and Colleges: FY 2008. See appendix table 5-9.

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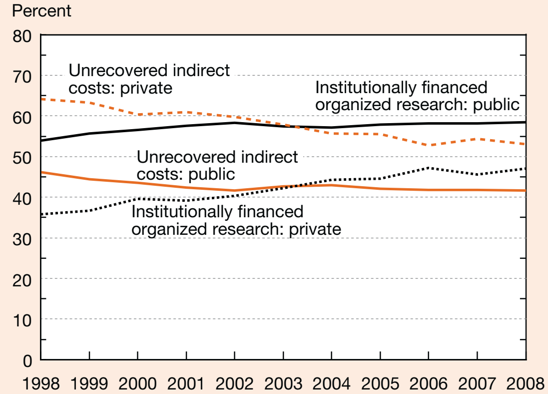
Figure 5-8
Components of institutional R&D expenditures for public and private academic institutions: 1998–2008



SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Research and Development Expenditures at Universities and Colleges, special tabulations (2009).

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The share of total R&D expenditures funded by all other sources was also comparable, at 7% and 9%, respectively.

Distribution of R&D Funds Across Academic Institutions

Academic R&D expenditures are concentrated in a relatively small number of institutions. In FY 2008, 679 institutions reported spending at least $150,000 on S&E R&D. Of these, the top-spending 20 accounted for 30% of total academic R&D spending and the top 100 for 80% of all academic R&D expenditures. Appendix table 5-10 presents the detailed distribution among the top 100 institutions. The concentration of academic R&D funds among the top 100 institutions has stayed constant over the past two decades (figure 5-9), as have the shares held by both the top 10 and the top 20 institutions.

It should be noted that the composition of the universities in each of these groups varies over time as universities increase or decrease their R&D activities. For example, 5 of the top 20 institutions in FY 1988 were no longer in the top 20 in FY 2008.

A similar concentration of funds is found among university performers of non-S&E R&D. The top 20 performers accounted for 36% of the total non-S&E R&D expenditures in FY 2008 (appendix table 5-11).

R&D Collaboration Between Higher Education Institutions

One way to measure the extent of collaboration among academic institutions is to examine how much of their total R&D expenditures was passed through to other academic institutions or received by institutions as subrecipient funding. R&D funds for joint projects that were passed through universities to other university subrecipients more than doubled from FY 2000 to FY 2008, from $699 million to $1.7 billion (figure 5-10; appendix table 5-12). This amount represents 3.3% of total academic R&D expenditures in FY 2008, compared with 2.3% of the total in FY 2000. In FY 2008, 90% ($1.5 billion) of these pass-through funds came from federal sources.

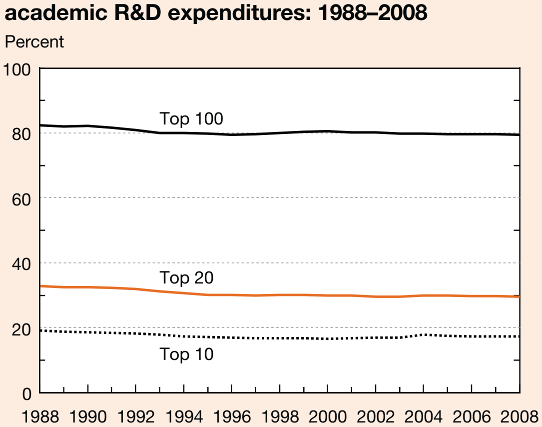
Not coincidentally, universities receiving pass-through funds from other universities likewise reported a rapid increase in subrecipient R&D expenditures between FY 2000 and FY 2008, from $669 million to $1.7 billion. More than 90% ($1.6 billion) of these subrecipient funds originated from federal sources.[16]

Overall, $3.5 billion was passed through institutions to all types of subrecipients in FY 2008 (including both academic and nonacademic institutions), and $3.9 billion was received as subrecipient funding from all types of pass-through entities (appendix table 5-12). Again, the majority of these funds were from federal sources (87% of pass-through funds and 90% of subrecipient expenditures).

Academic R&D Equipment

Research equipment is an integral component of the academic R&D enterprise. This section examines expenditures for moveable research equipment necessary for the conduct of organized research projects (e.g., computers, telescopes) and the federal role in funding these expenditures.

Figure 5-9
Academic R&D, by rank of university and college academic R&D expenditures: 1988–2008



SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Research and Development Expenditures at Universities and Colleges, special tabulations (2009).

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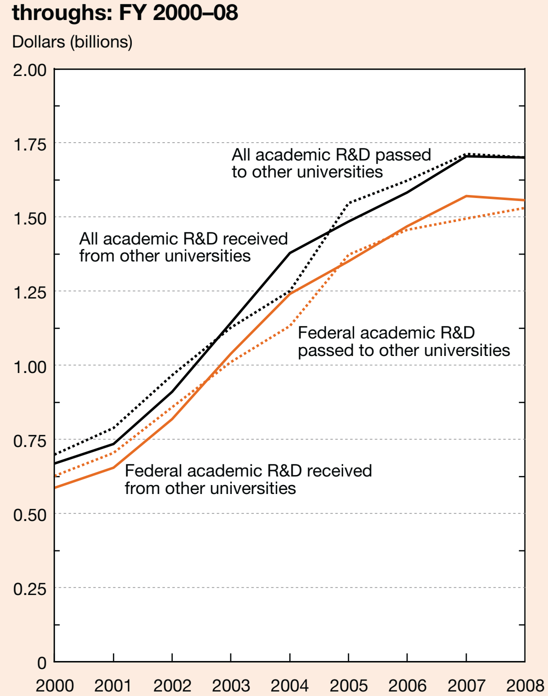
Figure 5-10
Total and federally funded academic R&D pass-throughs: FY 2000–08



SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Research and Development Expenditures at Universities and Colleges: FY 2008. See appendix table 5-12.

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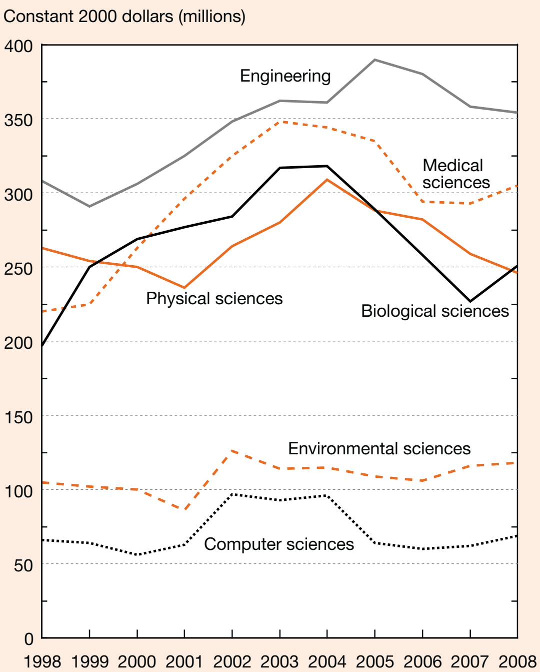
In FY 2008, about $1.9 billion in current funds was spent for academic research equipment (appendix table 5-13).[17] In constant dollars, this represents an increase of 1.0% from FY 2007 but a decline of more than 10% from the 2004 level. Overall, expenditures for R&D equipment have risen 61% in real dollars since 1985. About 80% of FY 2008 expenditures were concentrated in three fields: the life sciences (43%), engineering (23%), and the physical sciences (16%) (appendix table 5-13). After a period of steady growth between 2001 and 2004, equipment expenditures in the physical sciences, medical and biological sciences, and engineering have declined since FY 2005 (figure 5-11).

Federal funds for research equipment are generally received as part of research grants or as separate equipment grants. The share of federal funding for research equipment varies significantly by field (appendix table 5-14). The field of atmospheric sciences had the largest proportion of federally funded R&D equipment (85%) in FY 2008. The overall share of research equipment funded by the federal government fluctuated between 56% and 64% over the past two decades.

Figure 5-11
Current fund expenditures for research equipment at academic institutions, by field: 1998–2008



NOTE: See appendix table 4-1 for gross domestic product implicit price deflators used to convert current dollars to constant 2000 dollars.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Research and Development Expenditures at Universities and Colleges, FY 2008. See appendix table 5-13.

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Academic R&D Infrastructure

Physical infrastructure is an essential resource for the conduct of R&D. Not long ago, R&D capital infrastructure primarily consisted of instruments and research space such as laboratories and computer rooms. Consequently, the principal indicators of the state of research infrastructure have been square footage of designated research space and counts of instruments.

Over the past two decades, technological advances have brought fundamental changes not only in the methods of scientific research but also in the infrastructure necessary to conduct R&D. The infrastructure resulting from these technological innovations is often called *cyberinfrastructure.* Cyberinfrastructure may involve single resources such as a network used to transfer data, or it may involve a complex interaction of numerous resources resulting in sophisticated capabilities such as high-performance computation or remote use of scientific instrumentation. Regardless of how simple or complex this infrastructure may be, cyberinfrastructure has become an essential resource for science.

Cyberinfrastructure: Networking

Networking is a critical component of academic cyberinfrastructure that facilitates many research-related activities such as communication, data transfer, high-performance computation, and remote use of instrumentation.[18] In FY 2007, networking infrastructure was pervasive on many academic campuses and rapidly expanding in capability and coverage. Research-performing institutions[19] had greater numbers of connections, bandwidth, and campus coverage compared with earlier in the decade. Colleges and universities reported external network connections with greater bandwidth, faster internal network distribution speeds, more connections to high-speed networks, and greater wireless coverage on campus.

External Bandwidth

Early in the decade, some institutions reported no Internet1 connections of any kind, but by mid-decade, all institutions had connections and their bandwidths significantly increased. Between FY 2005 and FY 2007, the number of institutions with total Internet1 and Internet2 bandwidth of more than 100 megabits increased almost 30% (table 5-2). At the same time, the number of institutions with the fastest bandwidth speeds also continued to expand. The percentage of institutions with total Internet1 and Internet2 bandwidth of 1 gigabit or faster rose by more than 50% in FY 2007, reaching 34% of all institutions. If institutional estimates are realized, the percent of institutions with total bandwidth of 1 gigabit or faster will double between FY 2005 and FY 2008 to 42%.

Bandwidth capability increased across different types of academic institutions. However, the colleges and universities with the fastest bandwidths were dominated by doctorate-granting institutions. In FY 2007, all but one institution with total Internet1 and Internet2 bandwidth greater than 2.4 gigabits granted doctorates. Of all institutions with bandwidth of at least 1 gigabit, 83% were doctorate granting. This trend is likely to continue into FY 2008 and beyond. If institutions

Table 5-2
Bandwidth to commodity Internet (Internet1) and Internet2 at academic institutions: FY 2005–08
(Percent distribution)

Bandwidth	FY 2005	FY 2007	FY 2008
All bandwidth	100	100	100
No bandwidth	0	0	0
≤10 mb	6	3	2
11–100 mb	42	33	24
101–999 mb	30	31	30
1–2.5 gb	15	23	26
>2.5 gb	6	10	16
Other	*	1	1

* = >0 but <0.5%

gb = gigabits/second; mb = megabits/second

NOTES: Internet2 is a high-performance backbone network that enables the development of advanced Internet applications and the deployment of leading-edge network services to member colleges, universities, and research laboratories across the country. FY 2008 data estimated. Percents may not add to 100% because of rounding.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Science and Engineering Research Facilities, Fiscal Years 2005 and 2007.

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achieve their estimates for FY 2008, there will be a 70% increase in the number of institutions with bandwidths of greater than 2.4 gigabits. All but two will be doctorate granting.

Part of the increase in total bandwidth speed can be at least partially attributed to an increase in the number of connections to high-performance networks. The number of connections to Internet2 grew gradually over the decade, and by the end of FY 2007, a large majority (70%) of institutions had Internet2 connections. Between FY 2005 and FY 2007, the percentage of institutions with connections to the National Lambda Rail (NLR) increased 150% to approximately 25% of all institutions. After holding steady since the beginning of the decade, the number of institutions anticipating connections to federal government high-performance networks such as the Department of Energy's ESnet increased in FY 2007. Institutions have also begun connecting to more than one high-performance network. For example, in FY 2007, 25% had connections to both Internet2 and NLR.

Internal Institutional Networks

Similar to the trend of increased external bandwidth speed, internal network distribution speeds at academic institutions increased considerably. Since early in the decade, the percentage of institutions with slower bandwidth has rapidly decreased while the percentage with faster bandwidths has rapidly increased. In FY 2003, 66% of institutions had bandwidth of less than 1 gigabit; by the end of FY 2007, only 25% did (table 5-3). In FY 2003, no institutions had distribution speeds faster than 2.5 gigabits, but by FY 2007, 13% of academic institutions did. By FY 2007, the large majority (74%) of institutions had distribution speeds of 1 gigabit or faster.

In FY 2007, all but one academic institution had at least some wireless coverage in their campus buildings. In FY 2003, only 14% of these institutions had more than half of their building infrastructure covered by wireless; by FY 2007, the comparable figure was 59%.

Table 5-3
Highest internal network speeds, by highest degree granted: FY 2003–08
(Percent distribution)

Fiscal year and connection speed	All academic institutions	Highest degree granted	
		Doctorate	Nondoctorate
FY 2003	100	100	100
≤10 mb	2	3	2
11–999 mb	64	55	88
1–2.5 gb	33	43	10
2.6–9 gb	0	0	0
10 gb	0	0	0
>10 gb	0	0	0
Other	0	0	0
FY 2005	100	100	100
≤10 mb	0	0	1
11–999 mb	46	38	64
1–2.5 gb	50	56	35
2.6–9 gb	1	1	0
10 gb	3	4	0
>10 gb	*	*	0
Other	0	0	0
FY 2007	100	100	100
≤10 mb	1	1	1
11–999 mb	24	18	39
1–2.4 gb	61	63	55
2.5–9 gb	2	2	1
10 gb	10	14	3
>10 gb	1	2	0
Other	1	1	1
FY 2008	100	100	100
≤10 mb	1	1	1
11–999 mb	20	14	34
1–2.4 gb	51	51	51
2.5–9 gb	4	4	2
10 gb	21	26	10
>10 gb	2	3	1
Other	1	1	1

* = >0 but <0.5%

gb = gigabits per second; mb = megabits per second

NOTE: FY 2008 data estimated. Percents may not add to 100% because of rounding.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Science and Engineering Research Facilities, Fiscal Years 2003–07.

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Bricks and Mortar

Research Space

Research-performing colleges and universities continued a two-decade trend of increasing the amount of research space at their institutions.[20] By FY 2007, academic institutions had 192 million net assignable square feet (NASF) of research space (table 5-4). In recent years though, the rate of increase in research space has begun to slow. During

Table 5-4
S&E research space in academic institutions, by field: FY 1988–2007
(Millions of net assignable square feet)

Field	1988	1990	1992	1994	1996	1998	1999	2001	2003	2005	2007
All fields	112	116	122	127	136	143	148	155	172.7	185.1	191.9
Agricultural and natural resources	18	21	20	20	22	25	24	27	26.4	26.8	28.4
Biological and biomedical sciences	24	27	28	28	30	31	32	33	36.0	38.5	45.6
Computer and information sciences	1	1	2	2	2	2	2	2	3.1	4.1	4.9
Engineering	16	17	18	21	22	23	24	26	27.4	28.9	30.2
Health and clinical sciences	19	20	22	23	25	25	26	28	34.9	39.7	37
Mathematics and statistics	1	1	1	1	1	1	1	1	1.5	1.6	1.7
Physical sciences	22	22	23	24	25	26	27	27	29.3	29.6	29.3
Earth, atmospheric, and ocean sciences	6	6	7	7	7	8	8	8	8.9	8.6	8.5
Astronomy, chemistry, and physics	16	16	16	17	18	18	19	19	20.4	21.0	20.8
Psychology	3	3	3	3	3	3	3	4	4.4	4.8	5.0
Social sciences	3	3	3	3	4	5	5	5	5.7	6.3	6.2
Other sciences	4	2	2	2	2	3	3	3	3.8	4.9	3.7
Research animal space	na	na	9	11	12	12	13	na	16.7	16.5	18.3

na = not applicable, question not asked

NOTES: National Science Foundation, Division of Science Resources Statistics (NSF/SRS) bases S&E fields used in its Survey of Science and Engineering Research Facilities on those in National Center for Education Statistics (NCES) Classification of Instructional Programs (CIP). NCES updates CIP every 10 years. S&E fields used in FY 2007 Survey of Science and Engineering Research Facilities reflect NCES 2000 CIP update. For comparison of subfields in FY 2005 and FY 2007 surveys, see S&E Research Facilities: FY 2007, detailed statistical tables. Detail may not add to total because of rounding. Research animal space listed separately and also included in individual field totals.

SOURCE: NSF/SRS, Survey of Science and Engineering Research Facilities, Fiscal Years 1987–2007.

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FY 2005–07, institutions increased their research space at the slowest rate (3.7%) since FY 1998–99 (table 5-4). The rate of increase peaked in FY 2001–03 at 11%. Since then, the rate of increase has gradually declined.

Although the stock of research space increased overall in FY 2005–07, for the first time in 20 years, almost half of the S&E fields[21] experienced a decline in their research NASF. Particularly notable is that for the first time since FY 1988, the health and clinical sciences experienced an actual loss in research space of 7%. This decrease followed some of the largest increases in research space in any S&E field since the beginning of decade.

Even with the decline in FY 2007 though, the health and clinical sciences still had the second largest amount of research NASF (37 million) of all S&E fields. Only the biological and biomedical sciences had a greater amount of square footage (46 million), having increased 18% from the amount reported in FY 2005. In addition to the health and clinical sciences, the social sciences; the physical science subfields of earth, atmospheric and ocean sciences and astronomy, chemistry, and physics; and the fields classified as "other" experienced losses in research space. Only the earth, atmospheric, and ocean sciences had experienced a loss in the previous biennial period.

Continuing a trend that began in FY 2001, research space in the computer sciences once again experienced the largest rate of increase when compared with all other fields. In FY 2007, research space in the computer sciences increased 20% to approximately 5 million NASF.

New Construction

In conjunction with the slowdown in the increase in research space, the total amount of newly constructed research space also began to slow at the beginning of the decade (table 5-5). Since FY 2002–03, the total amount of new research space constructed declined by approximately 45%. However, within this overall broad decline, the amount and direction of change in new construction varied significantly by S&E field.

During FY 2006–07, initiation of construction of new research space was greatest in the biological and biomedical sciences (3 million NASF), the health and clinical sciences (2 million NASF), and engineering (1 million NASF). Relative to previous years, however, these three fields experienced a decline in the amount of new construction. The amount of newly constructed research space in engineering and in the biological and biomedical sciences declined from FY 2002–03 to FY 2004–05 and again, to a lesser extent, in FY 2006–07. In the health and clinical sciences, the amount of newly constructed research space declined 34% from FY 2002–03 to FY 2004–05. From FY 2004–05 to FY 2006–07, it declined another 48%.

Three fields of science reversed the decline in the amount of newly constructed space from earlier in the decade: the physical, computer, and agricultural sciences. The amount of newly constructed research space in the physical sciences increased 25% between FY 2004–05 and FY 2006–07, with the majority of new space located in astronomy, chemistry, and physics.

Table 5-5
New construction of S&E research space in academic institutions, by field and time of construction: FY 2002–07
(Millions of net assignable square feet)

Field	Started in FY 2002 or FY 2003	Started in FY 2004 or FY 2005	Started in FY 2006 or FY 2007
All fields	16.2	10.2	8.9
Agricultural and natural resources	0.8	0.4	0.5
Biological and biomedical sciences	4.0	3.2	3.0
Computer and information sciences	1.0	0.3	0.6
Engineering	2.2	1.5	1.3
Health and clinical sciences	5.0	3.3	1.7
Mathematics and statistics	*	*	*
Physical sciences	2.1	0.8	1.0
Earth, atmospheric, and ocean sciences	0.6	0.3	0.3
Astronomy, chemistry, and physics	1.5	0.5	0.7
Psychology	0.2	0.2	0.1
Social sciences	0.2	0.1	0.1
Other sciences	0.7	0.3	0.7
Research animal space	1.4	1.2	1.0

* = >0 but <50,000 net assignable square feet

NOTES: National Science Foundation, Division of Science Resources Statistics (NSF/SRS) bases S&E fields used in its Survey of Science and Engineering Research Facilities on those in National Center for Education Statistics (NCES) Classification of Instructional Programs (CIP). NCES updates CIP every 10 years. S&E fields used in FY 2007 Survey of Science and Engineering Research Facilities reflect NCES 2000 CIP update. For comparison of subfields in FY 2005 and FY 2007 surveys, see S&E Research Facilities: FY 2007, detailed statistical tables. Detail may not add to total because of rounding. Research animal space listed separately and also included in individual field totals.

SOURCE: NSF/SRS, Survey of Science and Engineering Research Facilities, Fiscal Years 2003–2007.

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In FY 2006–07, the funding of newly constructed research space returned to the pattern prevalent since the mid-1990s. Institutions use one or more sources to fund their capital projects, including the federal government, state or local governments, and the institutions' own funds. In the previous biennial period, the proportion of new construction costs funded by state and local governments dropped significantly relative to other funding sources, to 22%. Concurrently, funding by the institutions' own sources rose to 70% of all new construction funds ($5.8 billion).[22] In FY 2006–07, state and local governments returned to funding about one-third of new construction, while institutional internal sources funded about 60%. The remaining funding came from the federal government. The federal proportion of funding has remained relatively stable and small over time.

Doctoral Scientists and Engineers in Academia

The role of research in U.S. universities is both to create new knowledge and to educate students who will become the future generations of researchers and teachers (Association of American Universities 2006). Doctoral scientists and engineers in academia, and in particular faculty in U.S. colleges and universities, are an important aspect of academic R&D, as they generally engage in both research and teaching. The focus of this section is on the research aspects of doctoral scientists and engineers in academia.

This section examines trends in employment and labor market conditions of doctoral scientists and engineers in U.S. universities and colleges, with a particular focus on research activity. Trends in and characteristics of S&E doctoral researchers, including young investigators, are discussed as well as trends in government support for research. Chapter 3 provides more information on the workforce as a whole, and chapter 2 provides information on the output of students and degrees.

Trends in Academic Employment of Doctoral Scientists and Engineers

Academic employment of doctoral scientists and engineers grew over the past three decades, although growth was slower than in the business or government sectors. As a result, the share of all S&E doctorate holders employed in academia dropped from about 55% to 45% during the 1973–2006 period (NSB 2008).[23] The number of S&E doctorate holders employed in academia grew from 118,000 in 1973 to 272,800 in 2006 (table 5-6). Mirroring trends in R&D funding, life scientists accounted for much of the growth in academic employment. In engineering and many science fields, growth in academic employment slowed in the early 1990s but increased in recent years (figure 5-12).

Although full-time faculty positions continue to be the norm in academic employment, S&E doctorate holders increasingly are employed in part-time, postdoc, or full-time nonfaculty positions. From 1973 to 2006, the share of S&E doctorate holders employed in full-time faculty positions

Table 5-6
S&E doctorate holders employed in academia, by position: Selected years, 1973–2006
(Percent)

Position	1973	1983	1993	2006
All positions (number in thousands)	118.0	176.1	213.8	272.8
Full-time professors	36.1	39.7	37.4	31.3
Full-time associate professors	26.6	26.0	22.7	19.8
Full-time junior faculty	24.8	18.6	20.5	21.2
Full-time nonfaculty	6.4	7.6	10.4	13.4
Postdocs	3.6	4.7	6.2	8.5
Part-time positions	2.5	3.4	2.8	5.8

NOTES: Academic employment limited to U.S. doctorate holders employed at 2- or 4-year colleges or universities. Full-time junior faculty includes assistant professors and instructors, and full-time nonfaculty includes positions such as research associates, adjunct appointments, lecturers, and administrative positions. Total excludes those employed part time because they are students or retired.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations.

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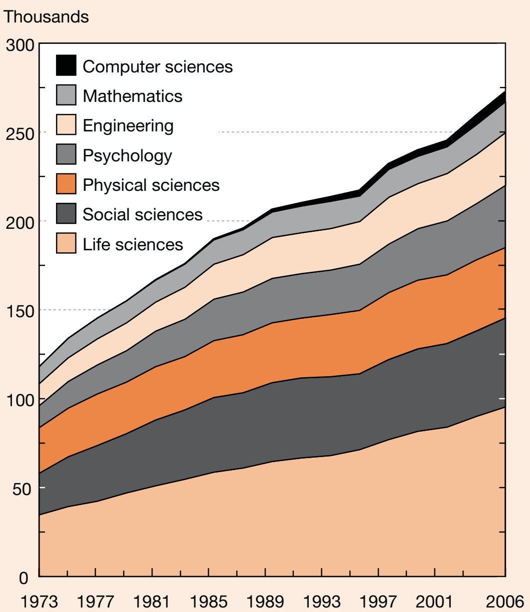
Figure 5-12
S&E doctorate holders employed in academia, by degree field: 1973–2006



NOTES: Academic employment limited to U.S. doctorate holders employed at 2- or 4-year colleges or universities and excludes those employed part time because they are students or retired. Physical sciences include earth, atmospheric, and ocean sciences.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations.

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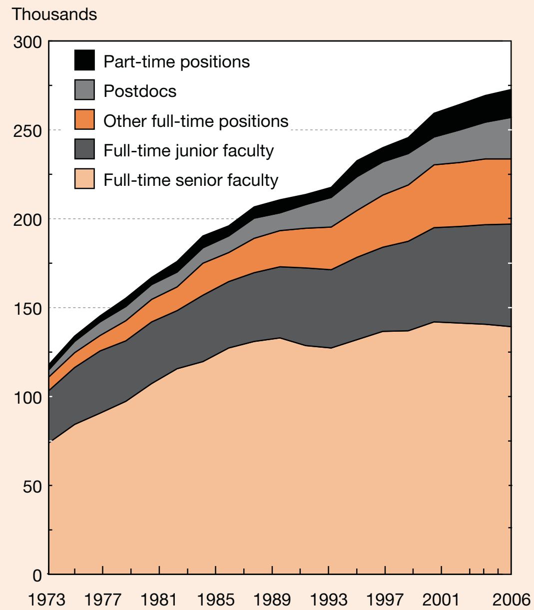
decreased while the share employed in postdoc or other full- and part-time positions increased (table 5-6 and figure 5-13). The full-time faculty share was 72% of all academic employment in 2006, down from 88% in the early 1970s. The full-time nonfaculty share rose from 6% in 1973 to 13% in 2006. Part-time positions accounted for only a small share (between 2% and 4%) of all academic S&E doctoral employment throughout most of the period before rising to almost 6% in 2006. Postdocs rose from 4% in 1973 to 9% of all academically employed S&E doctorate holders in 2006.

The lack of growth in the number of tenured and tenure-track positions in the life sciences, concurrent with increasing numbers of new doctorate holders, has been a subject of much focus in recent years (Benderly 2004, NRC 2005, Check 2007, Garrison and McGuire, 2008). Although the number of tenured full-time faculty in all fields increased from 90,700 in 1979 to 122,500 in 2006, their percentage of the academic workforce decreased from 69% to 62% (appendix table 5-15). This decline is largely accounted for by decreases in the life sciences (from 65% to 56%) and physical sciences (from 74% to 65%). Despite large increases in

Figure 5-13
S&E doctorate holders, by type of academic appointment: 1973–2006



NOTES: Academic employment limited to U.S. doctorate holders employed at 2- or 4-year colleges or universities. Senior faculty includes full and associate professors; junior faculty includes assistant professors and instructors. Other full-time positions include nonfaculty positions such as research associates, adjunct appointments, lecturers, and administrative positions. Part-time positions exclude those employed part time because they are students or retired.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations.

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academic R&D expenditures (appendix table 5-6) and in the number of doctorates granted in the life sciences (appendix table 2-26), the number of tenured and tenure-track life scientists has remained fairly stable since the late 1980s (appendix table 5-15).

Research as Either Primary or Secondary Work Activity

About two-thirds of doctoral scientists and engineers employed in academic institutions are engaged in research as either a primary or secondary work activity. From 1973 to 2006, the number of academic S&E doctorate holders reporting research as a primary or secondary work activity showed greater growth than the number reporting teaching as a primary or secondary activity (table 5-7). On average, the number of researchers grew 2.5% per year and the number of teachers grew 1.7% per year.

The life sciences accounted for much of this trend, with the number of life science researchers growing from 26,000 to 66,700, an average annual growth rate of 2.9% (table 5-8 and appendix table 5-16). Life scientists accounted for more than one-third of academic doctorate holders reporting research as a primary or secondary work activity in 2006. The number of researchers in computer sciences grew the fastest, at 16.3% from 1979 to 2006, although from a small base. The number of academic researchers in the physical sciences and mathematics grew more slowly, at average annual growth rates of 1.1% and 1.6%, respectively, from 1973 to 2006. Growth rates for academic researchers in all fields were greatest in the 1980s. From 1979 to 1989, the average

Table 5-7
S&E doctorate holders employed in academia with research or teaching as primary or secondary work activity, by degree field: 1973 and 2006
(Thousands)

	1973		2006		Growth rate 1973–2006 (%)	
Degree field	Research	Teaching	Research	Teaching	Research	Teaching
All fields	82.3	94.9	183.7	163.3	2.5	1.7
Physical sciences	18.8	20.2	26.9	24.1	1.1	0.5
Mathematics	6.8	8.8	11.4	13.8	1.6	1.4
Computer sciences	NA	NA	4.1	4.0	NA	NA
Life sciences	26.0	25.3	66.7	45.4	2.9	1.8
Psychology	7.3	9.8	20.5	21.1	3.2	2.3
Social sciences	14.3	20.2	32.8	37.9	2.5	1.9
Engineering	9.0	10.5	21.4	17.1	2.7	1.5

NA = not available

NOTES: Physical sciences include earth, atmospheric, and ocean sciences. Academic employment limited to U.S. doctorate holders employed at 2- or 4-year colleges or universities. Total excludes those employed part time because they are students or retired. Research includes basic or applied research, development, or design. Because individuals may select both a primary and a secondary work activity, they can be counted in both groups.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, 1973 and 2006, special tabulations.

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Table 5-8
Average annual growth rate for employment of S&E doctorate holders in academia reporting research as a primary or secondary work activity, by degree field: 1973–2006
(Percent)

Degree field	1973–2006	1973–79	1979–89	1989–99	1999–2006
All fields	2.5	1.5	5.4	1.0	1.3
Physical sciences	1.1	–0.5	3.5	0.6	–0.2
Mathematics	1.6	0.2	4.0	–0.4	2.0
Computer sciences	NA	NA	34.4	7.1	6.4
Life sciences	2.9	3.6	4.9	1.6	1.3
Psychology	3.2	2.1	5.7	1.8	2.5
Social sciences	2.5	0.4	7.6	0.1	0.8
Engineering	2.7	1.5	6.0	1.0	1.4

NA = not available

NOTES: Physical sciences include earth, atmospheric, and ocean sciences. Academic employment limited to U.S. doctorate holders employed at 2- or 4-year colleges or universities and excludes those employed part time because they are students or retired. Research includes basic or applied research, development, and design.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations.

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annual growth rate for doctoral scientists and engineers with research as a primary or secondary work activity was more than 5% per year, compared with less than 2% per year in the 1970s, 1990s, and 2000s.

Demographic Characteristics of Academic Researchers

The demographic composition of doctoral S&E researchers has changed over the past three decades, reflecting changes in the student population (see chapter 2 and appendix table 5-17). As women, minorities, and foreign-born researchers became an increasing share of academic researchers over the past two decades, men, and particularly white men, became a decreasing share.

Women in the Doctoral S&E Workforce. In 2006, 33% of all S&E doctorate holders employed in academia were women, up from 9% in 1973 (table 5-9). This rise reflects the increase in the proportion of women among recent S&E doctorate holders. Women hold a larger share of junior faculty positions than positions at either the associate or full professor rank (figure 5-14). In 2006, women constituted 25% of full-time senior faculty (full and associate professors) and 42% of full-time junior faculty (assistant professors and lecturers), the latter slightly higher than their share of recently earned S&E doctorates (table 5-9; see also "Doctoral Degrees by Sex" in chapter 2). However, their share of both junior and senior faculty positions rose substantially between 1973 and 2006. Although women are growing numbers of full-time faculty, they constitute more than half of academic S&E doctorate holders employed part time.

The percentage of women among full-time doctoral S&E research faculty is similar to the percentage of women among all S&E doctorate holders employed in academia. Women increased from 6% to 29% of full-time doctoral S&E research faculty from 1973 to 2006 (appendix table 5-16). Women's representation in some fields is higher than in others. Women make up almost half of full-time faculty researchers in psychology, about one-third of those in life sciences and social sciences,[24] and 11% of those in engineering (figure 5-15 and table 5-9).

Women are also a growing percentage of faculty at research institutions—up from 8% in 1977 to 23% in 2003—yet they remain less well represented at these institutions than at freestanding medical schools or at master's granting institutions (NSF/SRS 2008). (See sidebar "Women Faculty at Research Universities.") For a more complete discussion of the role of women, see *Women, Minorities, and Persons with Disabilities in Science and Engineering: 2009* (NSF/SRS 2009b).

Racial/Ethnic Groups in the Academic Doctoral Workforce. Asians and underrepresented minorities (blacks, Hispanics, and American Indians/Alaska Natives) constitute increasing shares of the academic doctoral workforce (table 5-10 and figure 5-16).[25] Between 1973 and 2006, the percentages of Asians and underrepresented minorities in the S&E academic doctoral workforce increased from 4% to 14% and 2% to 8%, respectively. These changes reflect increases in these groups' shares of recently earned doctorates. See "Doctoral Degrees by Race/Ethnicity" in chapter 2 for trends in doctoral degrees.

Table 5-9
Women as percentage of S&E doctorate holders, by position: Selected years, 1973–2006

Position and degree field	1973	1983	1993	2006
All positions	9.1	15.0	21.9	33.0
Full-time senior faculty	5.8	9.3	14.2	25.0
Full-time junior faculty	11.3	23.5	32.2	42.3
Full-time faculty researchers	6.3	11.4	17.7	28.6
Physical sciences	3.0	4.6	7.7	15.2
Mathematics	4.7	7.4	9.0	18.8
Computer sciences	NA	9.2	15.8	22.9
Life sciences	7.9	12.6	21.5	32.9
Psychology	13.1	23.8	35.4	48.9
Social sciences	8.2	16.3	21.5	33.7
Engineering	0.3	2.0	4.1	11.2
Full-time nonfaculty	14.5	23.1	30.2	36.2
Postdocs	14.3	30.1	30.8	40.8
Part-time positions	48.3	41.7	61.0	51.5

NA = not available

NOTES: Academic employment limited to U.S. doctorate holders employed at 2- or 4-year colleges or universities. Senior faculty includes full and associate professors; junior faculty includes assistant professors and instructors; and full-time nonfaculty includes positions such as research associates, adjunct appointments, lecturers, and administrative positions. Total excludes those employed part time because they are students or retired. Physical sciences include earth, atmospheric, and ocean sciences. Research includes basic or applied research, development, and design.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations.

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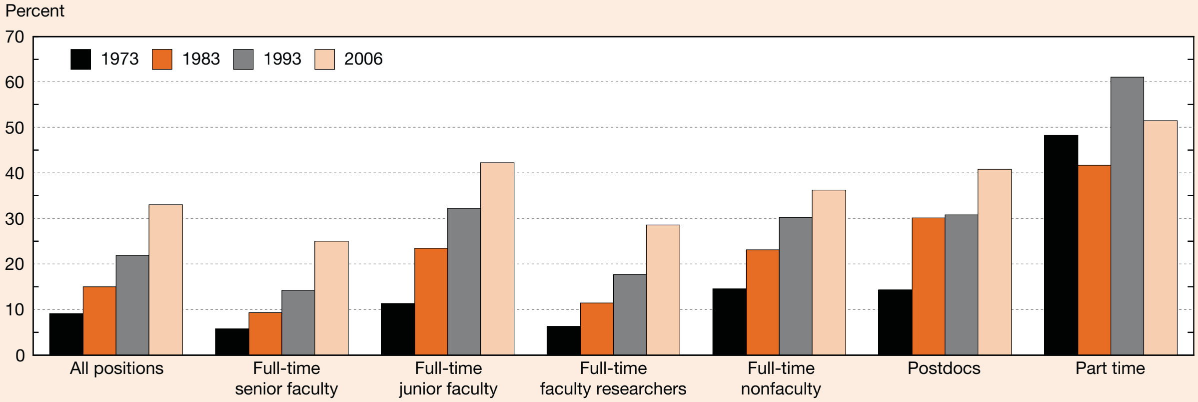
Figure 5-14
Women as percentage of S&E doctorate holders employed in academia with research as a primary or secondary work activity, by position: Selected years, 1973–2006



NOTES: Academic employment limited to U.S. doctorate holders employed at 2- or 4-year colleges or universities. Senior faculty includes full and associate professors; junior faculty includes assistant professors and instructors. Full-time nonfaculty includes positions such as research associates, adjunct appointments, lecturers, and administrative positions. Part-time positions exclude those employed part time because they are students or retired. Research includes basic or applied research, development, and design.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations.

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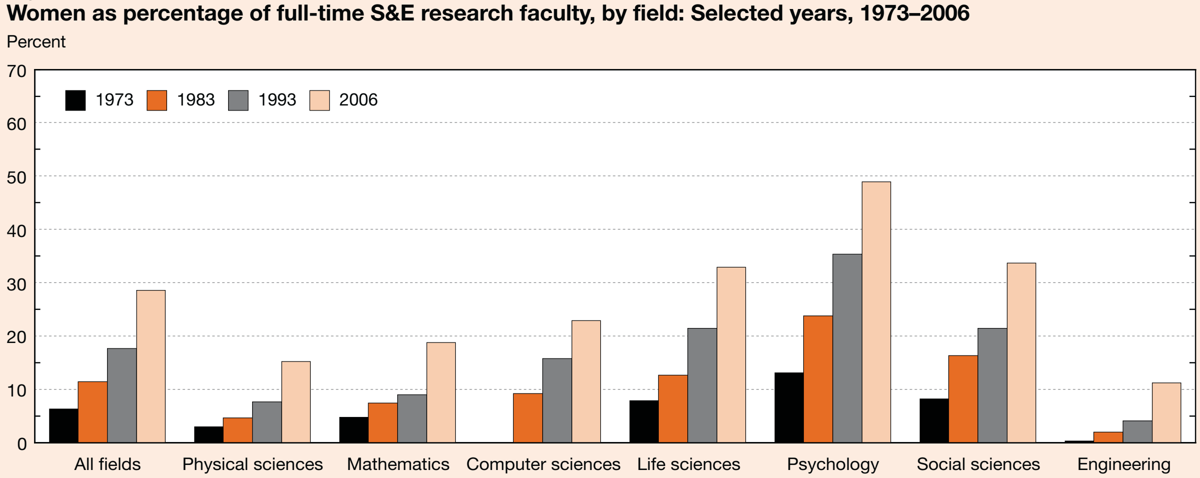
Among full-time doctoral research faculty, Asians increased from 4% to 13% from 1973 to 2006, and underrepresented minorities increased from 2% to 8%. Because of these increases, the proportion of full-time doctoral research faculty who are white decreased from 92% in 1973 to 79% in 2006 (appendix table 5-17).

Underrepresented minorities constituted a smaller share of employment at research universities than other racial/ethnic groups. In 2006, 35% of underrepresented minority S&E doctorate holders employed in academia were employed in research institutions, compared with 51% of Asian and 42% of white S&E doctorate holders employed in academia (NSB 2008). Notably, in 2003, the percentage of black S&E faculty employed at research universities (28%) was lower than the percentage employed at comprehensive universities (31%), largely because of this group's prevalence in historically black colleges and universities, most of which are comprehensive institutions (NSF/SRS 2006).[26]

Figure 5-15
Women as percentage of full-time S&E research faculty, by field: Selected years, 1973–2006



NOTES: Academic employment limited to U.S. doctorate holders employed at 2- or 4-year colleges or universities and excludes those employed part time because they are students or retired. Faculty includes full, associate, and assistant professors and instructors. Physical sciences include earth, atmospheric, and ocean sciences. Research includes basic or applied research, development, and design.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations.

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Women Faculty at Research Universities

In a congressionally mandated study of women faculty in research universities, the National Research Council (2009) found that women faculty do as well as or better than men in hiring, promotions, and access to university resources. The study focused on tenured or tenure-track faculty in 6 disciplines (biology, chemistry, civil engineering, electrical engineering, mathematics, and physics) at 89 research universities. Women constituted 12% of the faculty in the disciplines and universities studied. The study found that in these research universities, women were a lower percentage of applicants for tenured or tenure-track positions than they were of recent doctorates, especially in chemistry and biology. However, women were a higher percentage of interviewees than of applicants and a higher percentage of those hired than of interviewees. The study also found that women constituted a lower percentage of tenure candidates than of assistant professors, but that among those up for tenure review, women were more likely than men to receive tenure. The study found little difference in lab space, equipment, or percentage of time teaching or doing research and little difference in outcomes (e.g., honors, funding, salaries) of tenured or tenure-track faculty, with a few exceptions, including salaries of full professors and publications. Because of its specific mandate, the report did not address women who did not apply to research universities or those who left research universities, but noted the need for further research in these areas. By necessity, it did not address other types of academic employment, other types of academic institutions, or other issues affecting women's employment in academia, including dual careers, effects of children and family obligations, or institutional climate. Many other studies of women in academia address some of these issues (e.g., Long 2001; COSEPUP 2007; NSF 2004; Ginther 2001; Hosek et al. 2005; Rosser, Daniels, and Wu 2006; Fox 2005).

Table 5-10
Minorities as percentage of S&E doctorate holders, by position: Selected years, 1973–2006

	1973		1983		1993		2006	
Position and degree field	Under-represented minority	Asian	Under-represented minority	Asian	Under-represented minority	Asian	Under-represented minority	Asian
All positions	2.0	4.2	3.7	6.7	5.0	9.8	8.2	14.1
Full-time faculty	1.9	3.9	3.6	6.1	5.0	8.6	7.9	11.7
Full-time faculty researchers	1.7	4.3	3.2	7.4	4.8	10.1	7.6	13.5
Physical sciences	1.8	4.0	3.0	7.7	4.5	10.9	4.6	11.5
Mathematics	1.8	4.4	2.8	10.0	3.3	14.0	7.5	19.3
Computer sciences	NA	NA	NA	20.7	7.3	36.3	6.6	36.8
Life sciences	2.0	3.6	2.8	6.5	3.7	8.2	7.3	13.2
Psychology	1.7	S	3.1	1.9	5.7	2.2	8.5	4.3
Social sciences	1.7	4.3	4.8	5.4	7.0	6.2	9.9	8.1
Engineering	0.9	9.5	2.7	14.8	3.9	21.6	7.3	25.7
Postdocs	2.4	11.9	4.8	13.3	4.5	27.1	7.5	35.4
Other positions	2.9	5.7	4.1	8.2	5.3	8.9	9.3	13.7

NA = not available; S = data suppressed for reasons of confidentiality and/or reliability

NOTES: Underrepresented minority includes blacks, Hispanics, and American Indians/Alaska Natives. Asian includes Pacific Islanders through 1999, but excludes in 2001 through 2006. Academic employment limited to U.S. doctorate holders employed at 2- or 4-year colleges or universities. Faculty includes full, associate, and assistant professors plus instructors. Other positions include part-time positions and nonfaculty positions such as research associates, adjunct appointments, lecturers, and administrative positions. Total excludes those employed part time because they are students or retired. Physical sciences include earth, atmospheric, and ocean sciences. Research includes basic or applied research, development, and design.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations.

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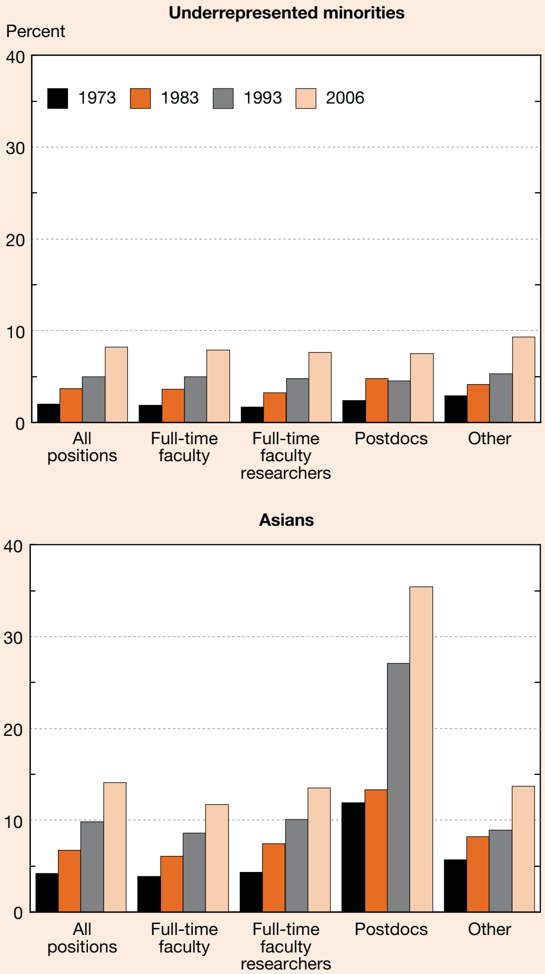
The distribution of racial/ethnic groups within S&E fields differs (appendix table 5-18). The percentage of underrepresented minorities among full-time faculty researchers ranges from about 5% in the physical sciences to about 10% in the social sciences. Asians are more heavily represented in engineering and computer sciences (where they constitute 26% and 37% of full-time faculty researchers, respectively) and represented at very low levels in psychology (4%) and social sciences (8%). For a more complete discussion of the role of Asians and underrepresented minorities, see *Women, Minorities, and Persons with Disabilities in Science and Engineering: 2009* (NSF/SRS 2009b).

Figure 5-16
Minorities as percentage of S&E doctorate holders, by position: 2006



NOTES: Underrepresented minorities include blacks, Hispanics, and American Indians/Alaska Natives. Academic employment limited to U.S. doctorate holders employed at 2- or 4-year colleges or universities. Faculty includes full, associate, and assistant professors plus instructors. Other includes part-time positions and nonfaculty positions such as research associates, adjunct appointments, lecturers, and administrative positions. Data exclude those employed part time because they are students or retired. Research includes basic or applied research, development, and design.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations.

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Foreign-Born Doctorate Holders in the Academic Doctoral S&E Workforce. Foreign-born S&E doctorate holders contribute substantially to academic R&D in the United States. Reliance by U.S. colleges and universities on foreign talent increased during the 1990s. Chapter 3 discusses more fully trends in immigration and employment characteristics of foreign-born scientists and engineers.

Approximately 31,400 noncitizens (permanent residents and temporary visa holders) and 31,300 naturalized U.S. citizens with a U.S. S&E doctorate were employed in academia in 2006 (appendix table 5-19). In addition, U.S. universities and colleges employ an unknown but probably large number of foreign-born S&E doctorate holders with doctorates from foreign universities.[27] (Chapter 3 of *Science and Engineering Indicators 2008* [NSB 2008] estimated that about 36% of foreign-born S&E doctorate holders had foreign-earned doctorates.) The discussion in this section is limited to U.S. doctorate holders.

Foreign-born S&E doctorate holders (both noncitizens and naturalized citizens) with U.S. S&E doctorates were 23% of the total academic doctoral S&E workforce in 2006 and close to half (47%) of academic postdocs (appendix table 5-19). Foreign-born S&E doctorate holders constitute a higher percentage of researchers than of all academically employed S&E doctorate holders. In 2006, they represented 27% of all academic researchers, regardless of rank or type of position, 24% of full-time faculty researchers, and 20% of all full-time faculty. U.S. S&E doctorate holders with temporary or permanent visas increased from about 4% of full-time faculty researchers with U.S. doctorates in 1973 to 10% in 2006 (appendix table 5-17).

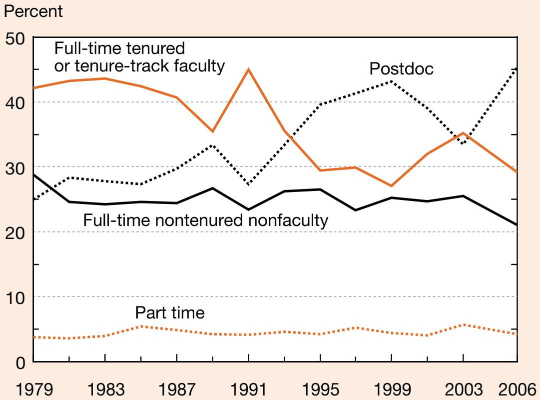
Foreign-born S&E doctorate holders with U.S. doctorates are more heavily concentrated in computer sciences, mathematics, and engineering than in other fields. These foreign-born doctorate holders account for more than half of all academic researchers and of full-time faculty researchers in computer sciences and for 39%–48% of all academic researchers and full-time faculty researchers in mathematics and engineering. In contrast, they represent 27% or less of all academic researchers and 21% or less of full-time faculty researchers in the life sciences, the physical sciences, psychology, and the social sciences (appendix table 5-19).

Recent S&E Doctorate Holders

Many doctoral candidates aspire to an academic, tenured faculty position, even though nonacademic employment has for many years exceeded that in universities and colleges, and the composition of academic hiring has changed as relatively fewer full-time faculty and relatively more part-time and nonfaculty are hired. Nevertheless, the relative availability of faculty positions is thought to have provided market signals to aspiring graduate students.

Over the past three decades, the share of recent doctorate holders (i.e., those with doctorates earned within 3 years of the survey) in full-time tenured or tenure-track faculty positions decreased and the prevalence of postdoc positions increased (figure 5-17). Between 1979 and 2006, the share of recent doctorate holders hired into full-time tenured or tenure-track faculty positions fell from 42% to 29%. Conversely, the overall share of recent S&E doctorate holders who reported being in postdoc positions rose from 25% to 45% during that period. (See the discussion of postdocs in chapter 3, "Science and Engineering Labor Force," for more

Figure 5-17
Recent S&E doctorate holders employed in academia, by position: 1979–2006



NOTES: Recent is defined as 1–3 years since doctorate. Academic employment limited to U.S. doctorate holders employed at 2- or 4-year colleges or universities and excludes those employed part time because they are students or retired. Full-time faculty includes full, associate, and assistant professors plus instructors. Full-time nontenured nonfaculty includes positions such as research associates, adjunct appointments, lecturers, and administrative positions.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations.

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information, including reasons for accepting a postdoc position and short-term career trajectory.) The share employed in part-time positions also rose in the 1970s and early 1980s but remained at roughly 5% from 1985 through 2006. The share employed in other full-time positions (e.g., adjunct faculty, lecturers, research associates, administrators) remained fairly stable over the period except for decreases from 1979 to 1981 and from 2003 to 2006.

The percentage of recent S&E doctorate holders and recent full-time S&E doctoral faculty engaged in research is higher than is the case for those who have had their doctorate for 12 or more years (table 5-11).[28] In some fields (e.g., computer sciences and engineering), research is a more prevalent activity among those who have had their doctorate for less than 8 years. In the life sciences, although research is most prevalent within 1 to 3 years of award of the doctorate, a relatively high percentage of doctorate holders remain in research, even among those with more experience.

Young Doctorate Holders With a Track Record

For those employed in academia 4–7 years after earning their doctorate, the trends are quite similar to those for doctorate holders who have had their degree for 1–3 years, although the former group's percentage employed in postdoc positions is much smaller and their percentage employed in faculty positions much larger. About half of S&E doctorate holders who have had their degree for 4–7 years had full-time tenured or tenure-track faculty positions in 2006, down from 64% in 1979 (figure 5-18). The percentage in postdoc positions rose from 6% to 15%, and the percentage in part-time positions rose from 3% to 6%. The percentage employed in full-time, non-tenure-track, nonfaculty positions changed little over time.

Government Support of Academic Doctoral Researchers

Academic researchers rely on the federal government for a majority of their overall research support. This section presents data from reports by S&E doctorate holders in academia about the presence or absence of federal support for their work.[29] However, nothing is known about the amount of funds received by individual researchers.

In 2006, 46% of full-time S&E doctoral faculty reported federal government support, about the same percentage as was the case in the late 1980s and only slightly higher than in 1973 (figure 5-19). As appendix table 5-20 shows, the percentage of S&E doctorate holders in academia who received federal support and the percentage of full-time S&E faculty who received federal support differed greatly across the S&E fields. In 2006, more than half of full-time S&E doctoral faculty in the physical sciences, the life sciences, and engineering and less than half of those in mathematics, computer sciences, psychology, and the social sciences received federal support. The percentage receiving federal support was lowest in social sciences (24%).

The percentage with federal support was higher among S&E doctorate holders in research universities (64%) and medical schools (70%) and lower among those employed in doctoral/research universities (28%), master's-granting universities (21%), and baccalaureate colleges (22%) (appendix table 5-20).

Federal Support of Young S&E Doctorate Holders in Academia

Early receipt of federal support is viewed as critical to launching a promising academic research career, yet federal support is less available to young S&E faculty with doctorates than to more established faculty, and the percentage of young S&E faculty with federal support is declining. Among full-time faculty, the percentage reporting federal support in 2006 was lower for those with recently earned doctorates than for all full-time faculty. Moreover, for younger faculty as well as all faculty, the percentage reporting federal support was lower in 2006 than in 1991 (a peak year) (figure 5-19). It should be pointed out that these data provide no information about whether an individual reporting federal support is being supported as a principal investigator on a research project or is participating in a more dependent status rather than as an independent researcher.

Among S&E doctorate holders with recently earned doctorates, those in full-time faculty positions were less likely to receive federal support than those in postdoc or other

Table 5-11
S&E doctorate holders employed in academia and full-time S&E faculty reporting research as primary or secondary work activity, by field and years since doctorate: 2006
(Percent)

Group and years since doctorate	All fields	Physical sciences	Mathematics and statistics	Computer and information sciences	Life sciences	Psychology	Social sciences	Engineering
S&E doctorate holders employed in academia								
All	67.3	68.0	65.7	70.5	69.8	58.5	65.4	72.4
1–3	78.9	84.5	78.9	79.6	80.0	67.8	71.5	88.3
4–7	72.0	76.2	78.2	79.7	73.0	59.7	68.4	80.7
8–11	69.3	69.9	73.5	63.5	72.7	56.8	69.1	73.1
≥12	63.2	62.7	59.6	65.0	65.8	56.6	62.9	65.5
Full-time S&E faculty								
All	68.6	66.5	68.4	74.0	69.9	63.6	68.8	70.9
1–3	73.5	64.4	71.1	83.9	66.6	69.0	79.9	82.0
4–7	74.0	73.9	81.5	85.1	70.1	68.1	73.1	85.6
8–11	73.4	74.7	80.3	68.1	75.1	64.0	74.1	73.3
≥12	66.0	64.0	63.4	68.0	69.1	61.8	65.4	66.3

NOTES: Academic employment limited to U.S. doctorate holders employed at 2- or 4-year colleges or universities and excludes those employed part time because they are students or retired. Faculty includes full, associate, and assistant professors plus instructors. Physical sciences include earth, atmospheric, and ocean sciences. Research includes basic or applied research, development, and design.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations.

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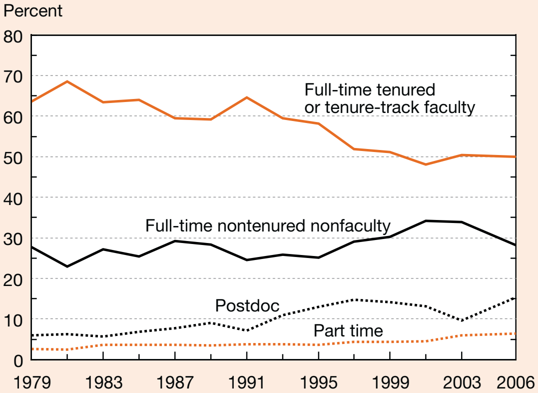
Figure 5-18
S&E doctorate holders employed in academia 4–7 years after receiving degree, by position: 1979–2006

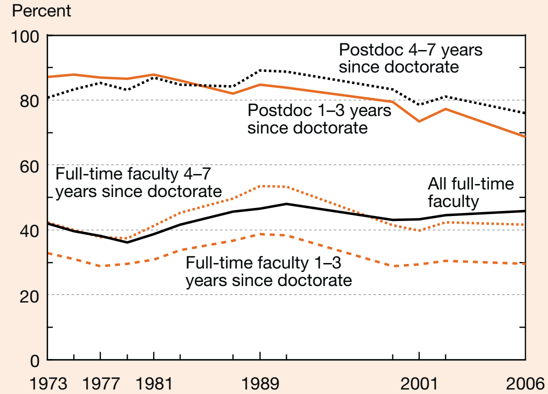


NOTES: Academic employment limited to U.S. doctorate holders employed at 2- or 4-year colleges or universities and excludes those employed part time because they are students or retired. Full-time faculty includes full, associate, and assistant professors plus instructors. Full-time nontenured nonfaculty includes positions such as research associates, adjunct appointments, lecturers, and administrative positions.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations.

Science and Engineering Indicators 2010

Figure 5-19
S&E doctorate holders employed in academia with federal support, by years since doctorate: 1973–2006



NOTES: 1985 and 1993–97 not comparable with other years and understate degree of federal support by asking whether work performed during week of April 15 was supported by government. In other years, question pertains to work conducted over course of year. Academic employment limited to U.S. doctorate holders employed at 2- or 4-year colleges or universities. Full-time faculty includes full, associate, and assistant professors plus instructors.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations.

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Table 5-12
S&E doctorate holders employed in academia with federal support, by degree field, years since doctorate, and position: 2006
(Percent)

Years since doctorate and position	All fields	Physical sciences	Mathematics and statistics	Computer and information sciences	Life sciences	Psychology	Social sciences	Engineering
1–3 years since doctorate								
All positions	49.1	66.1	36.6	37.4	55.9	45.2	18.8	58.9
Full-time faculty	29.5	39.2	18.4	23.7	31.6	38.1	16.5	42.5
Other full-time positions	48.7	64.7	S	64.3	56.2	32.2	32.9	50.7
Postdocs	68.6	77.8	60.5	100.0	67.7	66.0	27.0	74.4
4–7 years since doctorate								
All positions	47.3	58.2	32.0	45.3	57.5	35.7	21.5	63.9
Full-time faculty	41.7	52.8	29.7	43.0	49.9	36.6	21.9	61.3
Other full-time positions	43.4	59.2	29.5	49.9	49.4	31.0	22.5	62.6
Postdocs	76.0	72.2	79.5	S	77.4	88.8	S	87.9

S = suppressed, too few cases

NOTES: Academic employment limited to U.S. doctorate holders employed at 2- or 4-year colleges or universities. Recent doctorate holders earned doctorate within either 3 years or 4–7 years preceding survey. Full-time faculty includes full, associate, and assistant professors plus instructors. Other full-time positions include nonfaculty appointments such as research associates, adjunct appointments, lecturers, and administrative positions. Physical sciences include earth, atmospheric, and ocean sciences. Total includes part-time positions not shown separately but excludes those employed part time because they are students or retired.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations.

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full-time positions in 2006 (table 5-12). Almost half of those with recently earned doctorates reported receiving federal support, with 30% of those in full-time faculty positions, 49% in other full-time positions, and 69% in postdoc positions receiving federal support. Over the past three decades, the percentage of recent S&E doctorate holders in full-time faculty positions who have federal support remained fairly constant (except in the life sciences, where it declined), but the percentage in postdocs and in full-time nonfaculty positions with federal support declined (NSB 2008). The share of recent doctorate holders with federal support was relatively low in the social sciences and higher in the life and physical sciences and in engineering (table 5-12).

Among full-time faculty and postdocs in 2006, those who had received their doctorate 4–7 years earlier were more likely to receive federal support than those with recently earned doctorates (table 5-12). However, those who had received their doctorate 4–7 years earlier were also less likely to receive support in 2006 than in 1991 (figure 5-19 and table 5-13).

Collaborative Research

Research in many fields has increasingly involved collaboration of researchers, whether on large or small projects. Funding entities often encourage collaborative research, which can bring together people of different disciplines, different types of institutions, different economic sectors, and different countries. As noted in the section "R&D Collaborations Between Higher Education Institutions," R&D funds for joint projects that were passed through academic institutions to other institutions increased from FY 2000 to FY 2008, and most of the funds were from federal sources. This section explores S&E doctorate holders' reports of their collaboration with others. Information on trends in and the

Table 5-13
S&E doctorate holders employed in academia 4–7 years after receiving degree reporting receipt of federal support in previous year, by degree field: Selected years, 1973–2006
(Percent)

Degree field	1973	1983	1991	2006
All fields	47.1	50.1	57.4	47.3
Physical sciences	44.8	66.2	67.2	58.2
Mathematics	29.0	39.8	28.3	32.0
Computer sciences	NA	43.5	66.2	45.3
Life sciences	59.7	67.1	70.6	57.5
Psychology	37.8	32.3	38.8	35.7
Social sciences	29.0	28.1	36.6	21.5
Engineering	50.7	64.3	73.2	63.9

NA = not available

NOTES: 1991 used because 1993 not comparable with other years and understates degree of federal support by asking whether work performed during week of April 15 supported by government. In other years, question pertains to work conducted over course of year. Physical sciences include earth, atmospheric, and ocean sciences. Academic employment limited to U.S. doctorate holders employed at 2- or 4-year colleges or universities and excludes those employed part time because they are students or retired.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations.

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extent of coauthorship and collaboration using indicators developed from the research literature can be found later in this chapter under "Coauthorship and Collaboration."

In 2006, close to 70% of S&E full-time research faculty employed in academic institutions reported working in an immediate work group or team (appendix table 5-21).[30] Seventy-five percent worked with others elsewhere in the same organization, 58% worked with individuals in other organizations in the United States, and 29% worked with individuals located in other countries. Team work is most common among life scientists, physical scientists, and engineers (80%, 72%, and 77%, respectively) and least common among mathematicians (49%) and social scientists (50%). The percentage of full-time research faculty engaged in international collaboration was higher among those who were born outside the United States (34%) than among those born in the United States (28%). Differences between foreign and native-born researchers were even more pronounced in some fields, such as mathematics (36% compared with 21%), psychology (39% compared with 24%), and social sciences (41% compared with 28%). Although the differences in computer sciences appear large, they are not statistically significant.

Among full-time S&E research faculty, much of the international collaboration was by e-mail or telephone (98%), 52% involved travel abroad, 54% involved travel to the United States, and 38% involved Web-based or virtual technology (appendix table 5-22). Web-based or virtual technology was used far more by computer scientists (56%) than by other scientists and engineers engaged in international collaboration (38% overall). In many fields, a higher percentage of foreign-born than of U.S.-born research faculty travelled abroad for collaboration. More information on collaboration in scientific articles can be found in the next section.

Outputs of S&E Research: Articles and Patents

Chapter 2 of this volume discusses the human capital outputs of higher education in S&E. The present chapter focuses on the S&E functions of U.S. colleges and universities, including funding and performance, physical infrastructure, and human capital devoted to R&D. This section examines the intellectual output of academic S&E research using indicators derived from formal research articles and U.S. patent data.

Researchers have traditionally published the results of their work in the world's peer-reviewed S&E journals,[31] and article-level data from these journals are used here to explore total S&E research output by countries and—within the United States—by sectors of the economy.[32] These so-called *bibliometric* data are also useful for tracking trends in S&E research collaboration using coauthorship measures between and among departments, institutions, sectors, and countries. (See sidebar "Bibliometric Data and Terminology.") Finally, citations in more current research articles to previous research offer insight into the importance and impact of previous research.

The 2008 edition of *Indicators* (NSB 2008) focused attention throughout these bibliometric indicators on three large geographic units: the United States, the 27 members of the European Union, and a group of 10 fast-growing countries in Asia. This edition adjusts that particular organization of the data to focus instead on five S&E article-producing countries/regions that together account for more than four-fifths of the world total: the United States, the European Union, China, Japan, and eight countries/economies together referred to as the "Asia-8" (India, Indonesia, Malaysia, Philippines, Singapore, South Korea, Taiwan, and Thailand).

S&E researchers publish the results of their work in the peer-reviewed literature, and symbolic payment for their work is a citation to their article when it is used by future researchers (see Merton 1973). This recognition is uniquely valuable inside the scientific community, where it can be critical to career advancement, and does not necessarily reflect the value society might place on particular scientific findings.

In contrast, when researchers file for patent protection for a practical advance over "prior art" and the claim is granted in a successful patent, the patent owner obtains certain rights to the potential value of the advance. This chapter uses the patenting activities of U.S. academic institutions as another type of indicator of the outputs of academic S&E research. (Chapter 6, "Industry, Technology, and the Global Marketplace," discusses patenting by other sectors in "Global Trends in Patenting.") Because citations to the S&E literature in successful patents indicate the use of past research in practical advances, literature/patent linkage data illuminate patterns of the impacts of academic S&E research on potential technological development.

S&E Article Output

Between 1995 and 2007, the total world S&E article output as contained in the journals tracked by the Science Citation Index (SCI) and Social Sciences Citation Index (SSCI), which are analyzed in this chapter, grew at an average annual rate of 2.5% (table 5-14). Scientists and engineers in institutions in the member countries of the European Union authored or coauthored 32% of the world total in 2007,[33] followed by the United States with 28%. China, Japan, and the Asia-8 accounted for another 22% of the world total (appendix table 5-25).[34]

Growth in S&E article output across these five countries/regions has been uneven. Twelve-year growth rates in the mature economies of the U.S. (0.7%), Japan (1.0%), and the European Union (1.9%) have been lower than in the rapidly growing economies of the Asia-8 (9.0%) and China (16.5%) (appendix table 5-25; figure 5-20).

Exactly 200 countries or other entities[35] receive credit for publishing S&E articles (appendix table 5-23). A small number account for most of the publications.[36] Thus, table 5-14 shows that five countries (the U.S., China, Germany,

Bibliometric Data and Terminology

The article counts, coauthorship data, and citations discussed in this section are derived from S&E articles, notes, and reviews published in a set of scientific and technical journals tracked by Thomson Reuters in the Science Citation Index (SCI) and Social Sciences Citation Index (SSCI) (http://thomsonreuters.com/products_services/science/). The data exclude letters to the editor, news stories, editorials, and other material whose purpose is not the presentation or discussion of scientific data, theory, methods, apparatus, or experiments. The data are refined in a database prepared for NSF by The Patent Board™, formerly CHI Research, Inc., under a license agreement between The Patent Board™ and Thomson Reuters.

Journal Selection. Since *Science and Engineering Indicators 2004*, this section has used a changing set of journals that reflects the current mix of journals and articles in the world, rather than a fixed journals set. Thomson Reuters selects journals each year as described at http://www.thomsonreuters.com/products_services/science/free/essays/journal_selection_process/, and the selected journals become part of the SCI and SSCI portions of the Web of Science, a digital data product. Using citation data, Thomson Reuters then creates subsets of the SCI and SSCI that are available on CD-ROM and in print. These published data files are notable for the relatively high citation rank of the journals within their corresponding S&E subfields and the exclusion of journals of only regional interest, especially in the social sciences. Likewise, a declining citation rank can result in the removal of a journal from these highly selective data products.

Using the CD-ROM data, the Patent Board™ updates the NSF master file of journals; the number of journals analyzed by NSF from SCI/SSCI was 4,093 in 1988 and 5,266 in 2008. These journals give good coverage of a core set of internationally recognized peer-reviewed scientific journals. The coverage extends to electronic-only journals and print journals with electronic versions. In the period 1995–2008, the database contained 9,358,420 S&E notes, reviews, and articles.

Article Data. Except where noted, *author* means *departmental or institutional author.* Articles are attributed to countries or sectors by the country or sector of the institutional address(es) given in the articles. If no institutional affiliation is listed, the article is excluded from the counts in this chapter. Likewise, *coauthorship* refers to institutional coauthorship. An article is considered coauthored only if it shows different institutional affiliations or different departments of the same institution; multiple listings of the same department of an institution are considered as one institutional author. The same logic applies to cross-sector and international collaboration.

Two methods of counting articles are used: fractional and whole counts. *Fractional counting* is used for article and citation counts. In fractional counting, credit for multiauthor articles is divided among the collaborating institutions or countries based on the proportion of their participating departments or institutions. *Whole counting* is used for coauthorship data. In whole counting, each institution or country receives one credit for its participation in the article.

Several changes introduced in this edition of *Indicators* inhibit comparison with data from the same source used in previous editions.

- Previous editions reported data based on the year an article entered the database (tape year), not on the year it was published (publication year). NSF analysis has shown that, for the U.S. data, each new tape year file fails to capture from 10% to 11% of articles that will eventually be reported for the most current publication year; for some countries, the discrepancy is much larger. Here, data in the first section only ("S&E Article Output") are reported by publication year through 2007, which contains virtually complete data for this and prior publication years.
- Publication data in the remaining bibliometrics sections ("Trends in Output and Collaboration Among U.S. Sectors," "Coauthorship and Collaboration," and "Trends in Citation of S&E Articles") are reported by tape year through 2008.

The regions and countries/economies included in the bibliometric data are listed in appendix table 5-23. Data reported in this section are grouped into 13 broad S&E fields and 125 subfields, which are listed in appendix table 5-24.

Japan, and the United Kingdom) accounted for more than 50% of the total world S&E article output in 2007. The 45 countries in table 5-14—less than one-quarter of the countries in the data—produced 98% of the world total of S&E articles. Nevertheless, the data are constantly evolving to reflect changes in the makeup of nations around the world or the sudden appearance of an author from a heretofore nonpublishing country.[37]

Trends in Country and Regional Authorship

Steadily increasing investments in S&E education and research infrastructure in many countries, especially in Asia, have led to increased R&D in those countries and laid the groundwork for increased research productivity. As a result, scientists and engineers in those countries are increasingly prominent contributors to international peer-reviewed journals.

Table 5-14
S&E articles in all fields, by country/economy: 1995 and 2007

Rank	Country	1995	2007	Average annual change (%)	Percent of total (2007)	2007 cumulative world total (%)
na	World	564,645	758,142	2.5	na	na
1	United States	193,337	209,695	0.7	27.7	27.7
2	China	9,061	56,806	16.5	7.5	35.2
3	Japan	47,068	52,896	1.0	7.0	42.1
4	United Kingdom	45,498	47,121	0.3	6.2	48.3
5	Germany	37,645	44,408	1.4	5.9	54.2
6	France	28,847	30,740	0.5	4.1	58.3
7	Canada	23,740	27,799	1.3	3.7	61.9
8	Italy	17,880	26,544	3.3	3.5	65.4
9	Spain	11,316	20,981	5.3	2.8	68.2
10	South Korea	3,803	18,467	14.1	2.4	70.6
11	India	9,370	18,194	5.7	2.4	73.0
12	Australia	13,125	17,831	2.6	2.4	75.4
13	Netherlands	12,089	14,210	1.4	1.9	77.3
14	Russia	18,603	13,953	-2.4	1.8	79.1
15	Taiwan	4,759	12,742	8.6	1.7	80.8
16	Brazil	3,436	11,885	10.9	1.6	82.3
17	Sweden	9,287	9,914	0.5	1.3	83.6
18	Switzerland	7,220	9,190	2.0	1.2	84.9
19	Turkey	1,715	8,638	14.4	1.1	86.0
20	Poland	4,549	7,136	3.8	0.9	86.9
21	Belgium	5,172	7,071	2.6	0.9	87.9
22	Israel	5,741	6,622	1.2	0.9	88.7
23	Denmark	4,330	5,236	1.6	0.7	89.4
24	Finland	4,077	4,989	1.7	0.7	90.1
25	Greece	2,058	4,980	7.6	0.7	90.8
26	Austria	3,425	4,825	2.9	0.6	91.4
27	Iran	279	4,366	25.7	0.6	92.0
28	Mexico	1,937	4,223	6.7	0.6	92.5
29	Norway	2,920	4,079	2.8	0.5	93.1
30	Singapore	1,141	3,792	10.5	0.5	93.6
31	Czech Republic	1,955	3,689	5.4	0.5	94.0
32	Portugal	990	3,424	10.9	0.5	94.5
33	Argentina	1,967	3,362	4.6	0.4	94.9
34	New Zealand	2,442	3,173	2.2	0.4	95.4
35	South Africa	2,351	2,805	1.5	0.4	95.7
36	Ireland	1,218	2,487	6.1	0.3	96.1
37	Hungary	1,764	2,452	2.8	0.3	96.4
38	Egypt	1,388	1,934	2.8	0.3	96.6
39	Ukraine	2,516	1,847	-2.5	0.2	96.9
40	Chile	889	1,740	5.8	0.2	97.1
41	Thailand	340	1,728	14.5	0.2	97.3
42	Slovenia	434	1,280	9.4	0.2	97.5
43	Romania	678	1,252	5.2	0.2	97.7
44	Croatia	600	1,102	5.2	0.1	97.8
45	Serbia	NA	1,057	NA	0.1	98.0

na = not applicable; NA = not available

NOTES: Countries shown produced >1,000 articles in 2007. Countries ranked on 2007 total. Article counts from set of journals covered by Science Citation Index (SCI) and Social Sciences Citation Index (SSCI). Articles classified by year of publication and assigned to country/economy on basis of institutional address(es) listed on article. Articles on fractional-count basis, i.e., for articles with collaborating institutions from multiple countries/economies, each country/economy receives fractional credit on basis of proportion of its participating institutions. Detail does not add to total because countries omitted.

SOURCES: Thomson Reuters, SCI and SSCI, http://thomsonreuters.com/products_services/science/; The Patent Board™; and National Science Foundation, Division of Science Resources Statistics. See appendix table 5-25.

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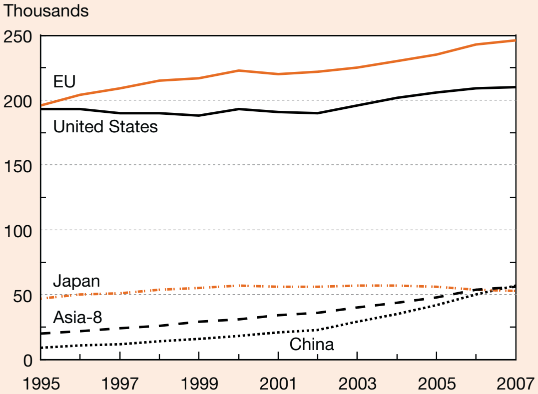
Figure 5-20
S&E article output, by major S&E publishing region/country: 1995–2007



EU = European Union

NOTES: Article counts from set of journals covered by Science Citation Index (SCI) and Social Sciences Citation Index (SSCI). Articles classified by year of publication and assigned to region/country/economy on basis of institutional address(es) listed on article. Articles on fractional-count basis, i.e., for articles with collaborating institutions from multiple countries/economies, each country/economy receives fractional credit on basis of proportion of its participating institutions. See appendix table 5-23 for countries/economies included in EU and Asia-8.

SOURCES: Thomson Reuters, SCI and SSCI, http://thomsonreuters.com/products_services/science/; The Patent Board™; and National Science Foundation, Division of Science Resources Statistics. See appendix table 5-25.

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Differences in recent rates of growth in article production are striking. In the major Asian countries, average annual growth rates between 1995 and 2007 were highest in China, at 17%. Across the Asia-8 countries, growth rates have been 9% annually for the same period (appendix table 5-25), led by Thailand (15%), South Korea (14%), Singapore (11%), and Taiwan (9%) (table 5-14). These growth rates mirror those in R&D expenditures and number of researchers. Japan's growth in article output averaged a modest 1% annually between 1995 and 2007. China's rapid growth rate in S&E article output propelled it in 2007 past the United Kingdom, Germany, and Japan to rank as the world's second-largest producer, up from 5th place in 2005 and 14th place in 1995 (appendix table 5-25).[38] During the same period, South Korea went from 22nd to 10th place.

These high rates of growth in S&E article authorship in Asia contrast with much slower rates for the world as a whole (2.5%), for countries with mature S&E infrastructures such as the United States (0.7%), and for the European Union (1.9%) (appendix table 5-25). Russia's article output decreased over the period, from 18,600 in 1995 to 14,000 in 2007, as did Ukraine's, from 2,500 to 1,800. Many of the other former republics of the Union of Soviet Socialist Republics (USSR) experienced negative growth on this indicator as well.

Countries within the European Union showed different trends in S&E article output between 1995 and 2007. Growth rates below 3% were common, for example, in Austria, Belgium, Denmark, Germany, and the Netherlands. Among the lowest rates of growth on this indicator were the United Kingdom (0.3%), France (0.5%), and Sweden (0.5%). Relatively high growth was experienced by the Czech Republic (5.4%), Greece (7.6%), Ireland (6.1%), Portugal (10.9%), and Spain (5.3%). Although not a member of the European Union, Turkey experienced one of the fastest growth rates in S&E article output in the world: 14.4% annually (from 1,700 articles in 1995 to 8,600 in 2007 (appendix table 5-25).

The countries in Central and South America together increased their S&E article output between 1995 and 2007 at an annual rate of 7.8%. Among the Central and South American countries that had more than 1,000 articles in 2007, Brazil had the highest growth rate (10.9%), followed by Mexico (6.7%), Chile (5.8%), and Argentina (4.6%). Brazil is also steadily increasing in rank among the world's S&E article producers: it was 23rd in 1995 and 16th in 2007 (table 5-14).

Across North Africa and the Middle East, only Egypt (2.8% annual growth since 1995), Israel (1.2%), and Iran (25.7%) produced substantial numbers of S&E articles in 2007. Iran's growth rate was the fastest of all nations (see sidebar "S&E Publishing Trends in Iran").

Research Portfolios of Top Article-Producing Countries/Regions

The S&E article output of the United States, the European Union, China, Japan, and the Asia-8 together accounted for 82% of the world total in 2007 (appendix table 5-25). A field-by-field comparison across these five countries/regions provides a snapshot of their research portfolios, and strong differences are evident. China, Japan, and the Asia-8 emphasize the physical sciences more than the United States and the European Union. China's S&E research articles in chemistry and physics accounted for almost one-half of its total article production in 2007 (table 5-15). In Japan, these two fields accounted for 36%, and in the Asia-8, 37%, compared with 17% for the United States and 25% for the European Union. The proportions of all five portfolios in astronomy (≤1.5%) and the geosciences (4.0%–5.5%) were similar.

These portfolios also vary in their emphasis on the life sciences (the biological, medical, agricultural, and other life sciences): the U.S. output in these fields accounted for 57% of its total, compared with 49% for the European Union, 25% for China, 45% for Japan, and 34% for the Asia-8 (table 5-15).

A third strong contrast across the five countries/regions is the emphasis on engineering: S&E research publications with authors in Asia are relatively more heavily concentrated in engineering (China at 16%, Japan at 11%, and the Asia-8 at 19%) than those with authors in the United States (7%) or the European Union (8%).

S&E Publishing Trends in Iran

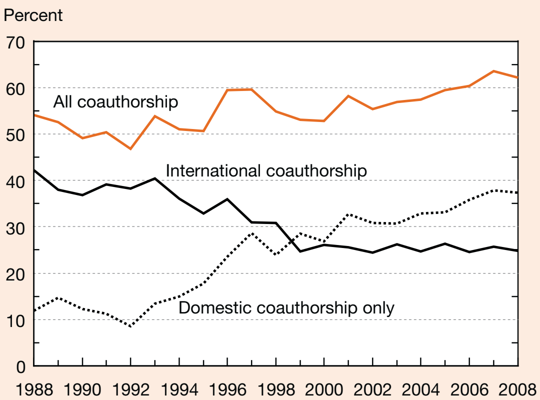
Iran-based authors produced 4,400 articles in 2007, and Iran's S&E publication growth rate has been the fastest in the world. Growth in publications has been strong across many fields, resulting in a 2007 publication portfolio weighted toward chemistry (30% of the total), engineering (15%), the medical sciences (14%), the biological sciences (14%), and physics (14%) (appendix tables 5-25 through 5-38).

Iran has an evolving science policy framework and a growing number of research institutions to carry out the framework (UNCTAD 2005). The country has a growing adult literacy rate (77% in 2003), but its economy is dominated by extraction and export of oil and gas. Current policy envisions a more diversified economy and a transition to development and production of petrochemicals and other high-technology products.

Iran's pattern of international coauthorship has mirrored that of other countries with immature S&E capabilities: they coauthor internationally at very high rates, but these rates decline as domestic capacity builds. Iran's rate of international coauthorship was 42% in 1988 but had declined to 25% in 2008, near the world average of 22% (figure 5-A; see also figure 5-21).

Despite a declining *rate* of international coauthorship Iran's total *number* of international coauthorships has been growing steadily, and coauthorships with each of its main foreign coauthor countries have also been growing. Table 5-B shows Iran's top five coauthoring countries in 2008.

Figure 5-A
Share of Iran's S&E articles coauthored domestically and internationally: 1988–2008



NOTES: Article counts from set of journals covered by Science Citation Index (SCI) and Social Sciences Citation Index (SSCI). Articles classified by year they entered database, rather than year of publication, and assigned to country on basis of institutional address(es) listed on article. Articles on whole-count basis, i.e., each collaborating institution or country credited one count. Internationally coauthored articles may also have multiple domestic coauthors.

SOURCES: Thomson Reuters, SCI and SSCI, http://thomsonreuters.com/products_services/science/; The Patent Board™; and National Science Foundation, Division of Science Resources Statistics, special tabulations.

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Table 5-B
International coauthorship with Iran, by top five coauthoring countries: 2008

	Articles	
Country	Number	Percent
World	1,514	100.0
United States	346	22.9
United Kingdom	232	15.3
Canada	217	14.3
Germany	129	8.5
France	113	7.5

NOTES: Article counts from set of journals covered by Science Citation Index (SCI) and Social Sciences Citation Index (SSCI). Articles classified by year they entered database, rather than year of publication, and assigned to countries on basis of institutional addresses listed on articles. Articles on whole count basis, i.e., each collaborating country credited one count.

SOURCES: Thomson Reuters, SCI and SSCI, http://thomsonreuters. com/products_services/science/; The Patent Board™; and National Science Foundation, Division of Science Resources Statistics, special tabulations.

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Coauthorship and Collaboration

Coauthored, collaborative articles with authors from different institutions and different countries have continued to increase, indicating increasing knowledge transfer or knowledge sharing among institutions and across national boundaries.[39, 40] The discussion begins with consideration of broad trends in coauthorship for the world as a whole, moves to regional patterns, and ends with an examination of country-level trends, including selected country-to-country coauthorship patterns and indexes of international collaboration. (Indicators of cross-sector coauthorship, which are available only for the United States, are examined below in the section "Trends in Output and Collaboration Among U.S. Sectors." Indicators of collaboration using different data are discussed earlier in this chapter under "Collaborative Research" in the "Doctoral Scientists and Engineers in Academia" section. For a consideration of the limitations of bibliometric techniques in identifying interdisciplinary S&E research, see the sidebar "Can Bibliometric Data Provide Accurate Indicators of Interdisciplinary Research?"

Article Author Names and Institutions

Between 1988 and 2005, the number of S&E articles, notes, and reviews grew by 60%, while the number of institutions and the number of author names on them both grew by more than 100% (NSB 2008, 08-01, figure 5-29). The trend continued in 2008. In all broad fields, the number of

Table 5-15
S&E research portfolios of selected regions/countries, by field: 2007
(Percent)

Field	U.S.	EU	China	Japan	Asia-8
All articles (*n*)	209,695	245,852	56,806	52,896	56,123
Engineering	6.9	8.1	16.0	11.1	19.1
Astronomy	1.4	1.5	0.7	0.8	0.5
Chemistry	7.5	12.0	24.5	16.1	18.0
Physics	9.3	13.4	24.0	19.7	18.9
Geosciences	5.5	5.3	4.3	4.0	4.0
Mathematics	1.9	2.7	3.3	1.3	1.5
Computer sciences	1.1	0.9	1.3	0.4	1.4
Agricultural sciences	1.8	2.4	2.0	2.2	2.4
Biological sciences	25.1	20.6	14.0	21.4	16.5
Medical sciences	27.8	25.2	8.4	21.3	14.9
Other life sciences	2.0	0.9	0.2	0.1	0.4
Psychology	4.3	2.6	0.3	0.7	0.6
Social sciences	5.4	4.3	0.8	1.0	1.6

EU = European Union

NOTES: Article counts from set of journals covered by Science Citation Index (SCI) and Social Sciences Citation Index (SSCI). Articles classified by year of publication and assigned to country on basis of institutional address(es) listed on article. Articles on fractional-count basis, i.e., for articles with collaborating institutions from multiple countries, each country receives fractional credit on basis of proportion of its participating institutions. See appendix table 5-23 for countries/economies included in EU and Asia-8. Percents may not add to 100% because of rounding.

SOURCES: Thomson Reuters, SCI and SSCI, http://thomsonreuters.com/products_services/science/; The Patent Board™; and National Science Foundation, Division of Science Resources Statistics. See appendix tables 5-25 through 5-38.

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author names per article increased (table 5-16). The average number of authors per paper was more than five in astronomy, physics, the biological sciences, and the medical sciences. Growth in the average number of coauthors was slowest in the social sciences (from 1.4 authors per paper in 1988 to 1.9 in 2008) and in mathematics (from 1.5 in 1988 to 2.0 in 2008). Unpublished NSF analyses show that in 2008, 90% of all S&E articles had at least two author names.

A closely related indicator, coauthored articles (i.e., articles with authors in different departments or institutions), has also increased steadily. Coauthored articles grew from 40% of the world's total S&E articles in 1988 to 64% in 2008 (figure 5-21). This growth has two parts. Coauthored articles that list only domestic institutions in the byline grew from 32% of all articles in 1988 to 42% in 2008. Articles that list institutions from more than one country, that is, internationally coauthored articles (which also may have multiple domestic institutional authors) grew from 8% to 22% over the same period. The remainder of this section focuses on these internationally coauthored articles.

International Coauthorship From a Regional Perspective

From the perspective of large article-producing countries/regions, interregional coauthorship has increased steadily.[41] From 1998 to 2008, interregional coauthorship increased as a percentage of the total article output of the United States (from 20% to 30%), the European Union (from 21% to 29%), Japan (17% to 26%), and the Asia-8 (22% to 27%) (table 5-17). Notably, China failed to increase on this indicator: as

Table 5-16
Authors per S&E article, by field: 1988, 1993, 1998, 2003, and 2008

Field	1988	1993	1998	2003	2008
All fields	3.1	3.4	3.8	4.2	4.7
Engineering	2.5	2.8	3.1	3.4	3.8
Astronomy	2.5	3.2	3.6	4.5	5.9
Chemistry	3.1	3.3	3.6	3.9	4.3
Physics	3.3	3.8	4.2	4.7	5.3
Geosciences	2.4	2.7	3.2	3.5	4.0
Mathematics	1.5	1.6	1.8	1.9	2.0
Computer sciences	1.9	2.0	2.3	2.6	3.0
Agricultural sciences	2.7	2.9	3.3	3.8	4.3
Biological sciences	3.3	3.7	4.2	4.6	5.3
Medical sciences	3.6	4.1	4.5	5.0	5.6
Other life sciences	2.0	2.1	2.4	2.9	3.2
Psychology	2.0	2.2	2.5	2.8	3.2
Social sciences	1.4	1.5	1.6	1.8	1.9

NOTE: Articles classified by year they entered database rather than year of publication.

SOURCES: Thomson Reuters, Science Citation Index and Social Sciences Citation Index, http://thomsonreuters.com/products_services/science/; The Patent Board™; and National Science Foundation, Division of Science Resources Statistics, special tabulations.

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Can Bibliometric Data Provide Accurate Indicators of Interdisciplinary Research?

To address the need for indicators of interdisciplinary research (IDR), NSF/SRS commissioned a panel of researchers* to review recent attempts to measure the growth of interdisciplinary S&E research. The panel reviewed 74 publications dealing with IDR. It concluded that, despite increased study of IDR in the literature, existing indicators of IDR based solely on bibliometric data were unsatisfactory for management and policy purposes and relied on an overly simplistic concept of IDR (Wagner, Roessner, and Bobb 2009; Wagner et al. 2009). The panel also found that problems with current data sources and analytical techniques raise questions about the validity of these measures.

The panel concluded that conceptualization of IDR involves both the *outputs* of research and research *processes*: it stressed that both social developments (e.g., new S&E working relationships, new career trajectories, new institutions) and cognitive developments (e.g., new theory, new ways of using existing data, new problem frameworks) are essential markers of IDR. Bibliometric data alone do not capture these dimensions of IDR.

The panel identified an emerging consensus that studies of IDR need measures of *knowledge integration* that could be applied to the work of either a team of researchers or an individual. However, they found limited agreement on what such integration entails and even less agreement on what would count as evidence of it.

The panel also assessed the limitations of current attempts at measurement of IDR, most of which use Thomson Reuters data products. These are organized into a structure based on the discipline of the *journal* in which articles are published. Studies then measure the "cognitive distance" reflected by the diversity of citations in their target data (authors, articles, journals) from the Thomson Reuters journal structure and treat this distance as the measure of IDR.

Alternative analytical techniques are under development. These use statistical and visualization techniques that seek to detect certain hidden structures in the data that may indicate IDR. However, these techniques still require validation. Bibliometric measures will also need to be supplemented by survey data, ethnographic studies, expert review, and other evidence to confirm the degree of interdisciplinarity in research output. Indicators of IDR may also vary depending on user needs. For example, measurements of IDR appropriate for projects, programs, and nations are likely to be different. The panel summarized its conclusions as follows (Wagner, Roessner, and Bobb 2009, p 9-10, 16):

- The Panel's consensus…is that it is premature to identify one or a small set of indicators or measures of interdisciplinary research…in part, because of a lack of understanding of how current attempts to measure IDR conform to the actual process and practice of interdisciplinary research, and the outcomes resulting from that practice.
- The literature is rich and maturing, but has not reached a point that permits meaningful assessment of IDR, especially for public policy and research management purposes.

*The assessment was performed by three researchers at SRI International, Caroline S. Wagner, J. David Roessner, and Kamau Bobb, working with the following experts on interdisciplinarity and visualization: Katy Börner, Indiana University; Kevin W. Boyack, SciTech Strategies, Inc.; Joann Keyton, North Carolina State University; Julie Thompson Klein, Wayne State University; and Ismael Rafols, University of Sussex. These eight researchers are referred to as the "panel" in this sidebar.

a percentage of its total S&E article output, China's interregionally coauthored articles declined from 26% in 1998 to 25% in 2008.

As a percentage of the world's interregionally coauthored articles, the shares of articles with a U.S., European Union, or Japanese institutional author declined slightly, giving way to a rise in the share of articles with an institutional author from China (from 6% to 13%) or the Asia-8 (from 9% to 14%). These changes in share of the world's interregional articles are similar to the changes in each region's share of all the world's articles.

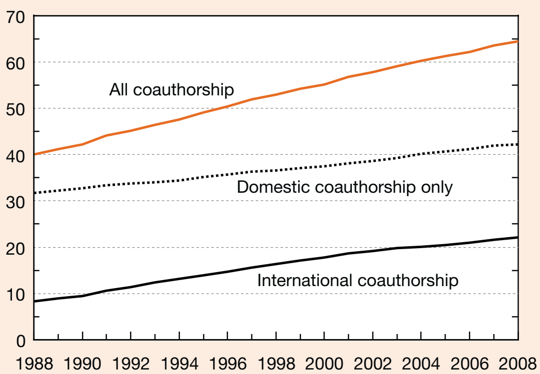
The other regions identified in table 5-17 tend to have a less-developed S&E infrastructure, and scientists and engineers in those regions tend more often to coauthor articles with colleagues in the more scientifically advanced regions/countries. For example, in 2008, 41% of all S&E articles with an institutional author from the Near East/North Africa (which includes Israel) had an author from another region, as did 61% of S&E articles with an institutional author from Sub-Saharan Africa (which includes South Africa). The following sections look more closely at coauthorship patterns of specific countries and country pairs.

International Coauthorship Patterns From a Country Perspective

When the region-level data discussed in the previous section are disaggregated to the country level, a richer picture of international S&E article coauthorship emerges. Table 5-18 displays the international coauthorship rates of countries that had institutional authors on at least 5% or more of the world's internationally coauthored S&E articles in 2008 (see also appendix tables 5-39 and 5-40).

The sheer volume of U.S. internationally coauthored articles dominates these measures: 30% of U.S. articles in 2008

Figure 5-21
Share of world S&E articles coauthored domestically and internationally: 1988–2008



NOTES: Article counts from set of journals covered by Science Citation Index (SCI) and Social Sciences Citation Index (SSCI). Articles classified by year they entered database, rather than year of publication, and assigned to country/economy on basis of institutional address(es) listed on article. Articles on whole-count basis, i.e., each collaborating institution or country credited one count. Internationally coauthored articles may also have multiple domestic coauthors.

SOURCES: Thomson Reuters, SCI and SSCI, http://thomsonreuters.com/products_services/science/; The Patent Board™; and National Science Foundation, Division of Science Resources Statistics, special tabulations.

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were internationally coauthored, and U.S.-based researchers were coauthors of 43% of the world's total internationally coauthored articles. The next highest percentages of the world's coauthored articles were held by Germany and the United Kingdom, each at 19% of the world total.

Even higher rates of international coauthorship are evident among the countries of the European Union and in Switzerland. Both Japan's and the Asia-8's international coauthorship rates have increased over the past 10 years.

What accounts for specific coauthorship relationships? Narin and colleagues (1991) concluded that "the direction of international coauthorship is heavily dependent on linguistic and historical factors." Coauthorship data suggest that geography, cultural relations, and the language of particular pairs or sets of countries play a role (Glänzel and Schubert 2005; Schubert and Glänzel 2006), and these preferences have been evolving over time (Glänzel 2001). In more recent years, European Union policies and incentives that foster intra-European Union, cross-border collaboration are also partly responsible for some high rates of coauthorship. The discussion below in the section "International Collaboration in S&E" identifies strong coauthorship relations in specific country pairs across the world, based on the strength of their coauthorship rates.

Table 5-17
Interregional collaboration on S&E articles: 1998 and 2008
(Percent)

Region/country	Share of region's/country's total article output 1998	Share of region's/country's total article output 2008	Share of world's interregional articles 1998	Share of world's interregional articles 2008
United States	20	30	57	55
EU	21	29	66	61
Other Western Europe	43	48	12	12
Asia	18	23	25	34
China	26	25	6	13
Japan	17	26	13	11
Asia-8	22	27	9	14
Other Asia	62	65	1	1
Other former USSR	31	42	11	7
Near East/North Africa	39	41	7	7
Central/South America	39	40	9	9
Sub-Saharan Africa	47	61	3	4
Other	31	43	20	21

EU = European Union; USSR = Union of Soviet Socialist Republics

NOTES: Interregionally coauthored articles have at least one collaborating institution from indicated region/country and an institution from outside that region/country. Article counts from set of journals covered by Science Citation Index (SCI) and Social Sciences Citation Index (SSCI). Articles classified by year they entered database, rather than year of publication, and assigned to region/country on basis of institutional address(es) listed on article. Articles on whole-count basis, i.e., each collaborating region/country credited one count. See appendix table 5-23 for countries/economies included in each region. Detail adds to more than 100% because articles may have authors from more than two countries/economies. Asia computed as sum of collaboration among China, Japan, Asia-8, and Other Asia.

SOURCES: Thomson Reuters, SCI and SSCI, http://thomsonreuters.com/products_services/science/; The Patent Board™; and National Science Foundation, Division of Science Resources Statistics, special tabulations.

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International Coauthorship With the United States

Table 5-19 lists the 31 countries whose institutions appeared on at least 1% of U.S. internationally coauthored articles in 2008. U.S. authors are most likely to coauthor with colleagues from the United Kingdom (13.9%), Germany (12.7%), Canada (12.0%), and China (10.4%—up from 3.5% in 1998).

Table 5-18 shows that the rate at which U.S. researchers participate in international collaboration is below that of many countries with smaller science establishments. However, because of the size of the S&E establishment in the United States, the share of U.S. internationally coauthored articles that were coauthored with any other country is lower than the share of the other country's internationally coauthored articles that were coauthored with U.S. researchers (table 5-19). For example, 3% of U.S. scientists who coauthored internationally in 2008 collaborated with Israeli

Table 5-18
International collaboration on S&E articles, by selected country/economy: 1998 and 2008
(Percent)

	Share of country's/ economy's total article output		Share of world's internationally coauthored articles	
Country/economy	1998	2008	1998	2008
United States	20	30	44	43
EU				
France	38	52	16	14
Germany	36	51	20	19
Italy	38	45	10	9
Netherlands	40	52	7	6
Spain	34	45	6	8
United Kingdom	32	49	19	19
Other Western Europe				
Switzerland	50	65	6	6
Asia				
China	26	25	4	11
Japan	17	26	10	9
Asia-8	23	30	7	12
Other				
Australia	31	45	5	7
Canada	34	46	10	10

EU = European Union

NOTES: Internationally coauthored articles have at least one collaborating institution from indicated country/economy and an institution from outside that country/economy. Article counts from set of journals covered by Science Citation Index (SCI) and Social Sciences Citation Index (SSCI). Articles classified by year they entered database, rather than year of publication, and assigned to country/economy on basis of institutional address(es) listed on article. Articles on whole-count basis, i.e., each collaborating country/economy credited one count. Countries/economies with less than 5% of 2008 international total omitted. See appendix table 5-23 for countries/economies included in Asia-8, which in this table is treated as a single country. Detail adds to more than 100% because articles may have authors from more than two countries/economies.

SOURCES: Thomson Reuters, SCI and SSCI, http://thomsonreuters.com/products_services/science/; The Patent Board™; and National Science Foundation, Division of Science Resources Statistics, special tabulations.

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counterparts; the corresponding figure for Israel, with its much smaller scientific infrastructure, is 52%. Again, 51% of scientists and engineers in Canada who coauthored internationally collaborated with U.S. colleagues, but only 12% of U.S. international coauthorship was with colleagues at Canadian institutions;[42] linguistic, geographic, and other ties combine to facilitate these collaborations.

Notable changes in these patterns of U.S. international coauthorship parallel changes in other indicators discussed in this section. As China's total S&E article output grew rapidly, so did its coauthorship with U.S. authors: the U.S. share of China's internationally coauthored articles increased about 6 percentage points over the past decade, and China's share of U.S. internationally coauthored articles increased almost 7 percentage points (table 5-19). U.S. scientists and engineers lost relative share of international coauthorship with some countries/economies, notably India, South Korea, Taiwan, and Japan, as their counterparts in those countries/economies broadened the geographic scope of their collaborative relations.

International Collaboration in S&E

In developing indicators of international collaboration between countries and across regions, researchers have developed statistical techniques that account for unequal sizes in countries' S&E article output and coauthorship patterns (Glänzel and Schubert 2004). One of the simplest is the index of international collaboration (table 5-20), which is defined as the ratio of country A's rate of collaboration with country B divided by country B's rate of total international coauthorship (Narin, Stevens, and Whitlow 1991). Indexes above 1 represent rates of coauthorship that are higher than expected, and indexes below 1 indicate rates of coauthorship that are lower than expected. For example, if country B produces 12% of internationally coauthored articles, and 12% of country A's coauthored articles are with country B, the index of international collaboration is 12%/12% = 1.0. The indexes for all pairs of countries that produced more than 1% of all internationally coauthored articles in 2008 are shown in appendix table 5-41.

Table 5-20 lists the international collaboration index for selected pairs of countries. In North America, the Canada-United States index shows a rate of collaboration that is slightly greater than would be expected based solely on the number of internationally coauthored articles shared by these two countries, and the index has changed little over the past decade. The Mexico-United States index is just about as would be predicted and is also stable.

Collaboration indexes between pairs of countries on opposite sides of the North Atlantic are all low and have changed little over the decade. In Europe, collaboration patterns are mixed, but most have increased over the decade, indicating growing integration across the European Union in terms of S&E article publishing. Among the large publishing countries of Germany, the United Kingdom, and France, collaboration was less than expected but grew in all three countries over the decade.

The Scandinavian countries[43] increased their coauthorship indexes with many countries in Europe (appendix table 5-41), and within Scandinavia, the indexes are among the highest in the world and, overall, have been growing stronger (table 5-20).

Cross-Pacific collaboration patterns are mixed. Japan-United States collaboration fell below the expected value over the decade, while the China-United States index rose to near 1. U.S. collaboration indexes with South Korea and Taiwan declined but remained higher than expected in both cases. Canadian scientists and engineers were less likely than their U.S. neighbors to have coauthored with colleagues in Asia. Mexico's collaboration with Argentina is almost four times higher than expected, at 3.74 in 2008. In South America, the collaboration index of Argentina-Brazil, at 5.32, is one of the highest in the world.

Table 5-19
International coauthorship of S&E articles with the United States, by selected country/economy: 1998 and 2008
(Percent)

	1998		2008	
Country/economy	U.S. share of country's/ economy's international articles	Country/ economy share of U.S.'s international articles	U.S. share of country's/ economy's international articles	Country/ economy share of U.S.'s international articles
World	43.9	na	43.3	na
United Kingdom	29.6	12.5	32.0	13.9
Germany	29.9	13.7	29.7	12.7
Canada	53.2	11.6	51.2	12.0
China	35.8	3.5	42.1	10.4
France	24.7	8.7	26.0	8.3
Japan	45.2	10.4	38.7	7.9
Italy	31.8	7.0	32.5	7.1
Australia	35.1	4.3	33.6	5.2
South Korea	60.6	2.9	53.5	5.0
Spain	24.9	3.4	27.1	4.8
Netherlands	29.9	4.4	30.5	4.5
Switzerland	31.2	4.2	31.6	4.3
Sweden	29.0	3.6	29.2	3.2
Israel	55.1	3.9	52.3	2.8
Brazil	38.1	2.3	38.5	2.8
Russia	24.7	3.9	27.3	2.7
Taiwan	63.4	1.7	53.4	2.5
Belgium	23.1	2.1	24.4	2.3
India	40.6	1.9	34.3	2.3
Denmark	30.5	2.2	30.2	1.9
Mexico	44.5	1.6	44.8	1.7
Poland	25.0	1.8	26.4	1.7
Austria	25.3	1.5	24.5	1.6
Norway	29.1	1.2	29.6	1.4
Finland	27.5	1.5	27.1	1.4
Greece	29.6	0.9	33.4	1.3
New Zealand	34.7	1.0	34.9	1.2
Turkey	38.0	0.6	41.7	1.2
Singapore	28.7	0.4	30.3	1.1
Argentina	35.1	0.9	34.9	1.1
South Africa	31.1	0.7	34.8	1.1

na = not applicable

NOTES: Internationally coauthored articles have at least one collaborating institution from indicated country/economy and an institution from outside that country/economy. Article counts from set of journals covered by Science Citation Index (SCI) and Social Sciences Citation Index (SSCI). Articles classified by year they entered database, rather than year of publication, and assigned to country/economy on basis of institutional address(es) listed on article. Articles on whole-count basis, i.e., each collaborating country/economy credited one count. Countries/economies ranked on percentage of their share of U.S.'s international articles in 2008; countries/economies with less than 1% of U.S.'s 2008 international articles omitted.

SOURCES: Thomson Reuters, SCI and SSCI, http://thomsonreuters.com/products_services/science/; The Patent Board™; and National Science Foundation, Division of Science Resources Statistics. See appendix tables 5-39 and 5-40.

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Collaboration indexes within Asia and across the South Pacific between the large article producers are generally higher than expected but with only minor changes over the past decade. Australia's coauthorships are strongly linked to New Zealand, at nearly four times the expected rate of coauthorship. Two strongly coauthoring pairs are South Korea-Japan and Australia-Singapore. India's collaboration index with South Korea grew from 1.61 to 2.19 over the past decade.

Trends in Output and Collaboration Among U.S. Sectors

In the U.S. innovation system, ties between and among universities, industry, and government have been beneficial for all sides. These ties include the flows of knowledge among these sectors, for which research article outputs and collaboratively produced articles are proxy indicators. S&E articles authored at academic institutions have for decades accounted for

Table 5-20
Index of international collaboration on S&E articles, by selected country/economy pair: 1998 and 2008

Country/economy pair	International collaboration index 1998	2008
North/South America		
Canada–U.S.	1.21	1.18
Mexico–U.S.	1.01	1.03
U.S.–Brazil	0.87	0.89
Argentina–Brazil	4.33	5.32
Mexico–Argentina	2.99	3.74
North Atlantic		
UK–U.S.	0.67	0.74
Germany–U.S.	0.68	0.68
France–U.S.	0.56	0.60
Canada–France	0.63	0.74
Europe		
France–Germany	0.74	0.91
France–UK	0.73	0.87
Germany–UK	0.68	0.86
Belgium-Netherlands	2.50	2.68
Italy–Switzerland	1.51	1.38
Poland–Czech Republic	2.15	3.48
Hungary–Germany	1.23	1.34
Germany–Czech Republic	1.27	1.46
Scandinavia		
Finland–Sweden	3.39	3.98
Norway–Sweden	4.10	3.96
Sweden–Denmark	2.88	3.38
Finland–Denmark	2.36	3.15
Pacific Rim		
Japan–U.S.	1.03	0.89
China–U.S.	0.82	0.97
South Korea–U.S.	1.38	1.23
Taiwan–U.S.	1.44	1.23
China–Canada	0.66	0.73
Japan–Canada	0.59	0.55
Asia/South Pacific		
China–Japan	1.53	1.38
South Korea–Japan	1.99	1.90
Australia–Singapore	1.93	1.70
Australia–China	1.05	1.14
Australia–New Zealand	4.28	3.80
India–Japan	0.94	1.12
India–South Korea	1.61	2.19

UK = United Kingdom

NOTES: International collaboration index is first country's rate of collaboration with second country divided by second country's rate of international coauthorship. Article counts from set of journals covered by Science Citation Index (SCI) and Social Sciences Citation Index (SSCI). Articles classified by year they entered database, rather than year of publication, and assigned to country/economy on basis of institutional address(es) listed on article. Articles on whole-count basis, i.e., each collaborating country/economy credited one count.

SOURCES: Thomson Reuters, SCI and SSCI, http://thomsonreuters.com/products_services/science/; The Patent Board™; and National Science Foundation, Division of Science Resources Statistics. See appendix table 5-41.

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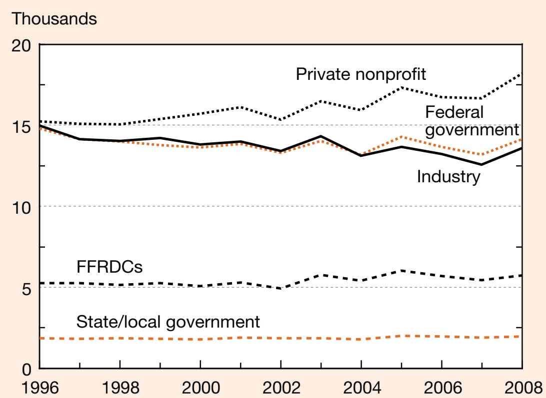
more than 70% of all U.S. articles (76% in 2008) (appendix table 5-42). This section contrasts U.S. academic authorship with nonacademic authorship, including output trends by sector and the extent of coauthorship, both between U.S. sectors and between U.S. sectors and authors abroad.

Article Output by Sector

Total annual S&E articles by authors in U.S. nonacademic sectors changed little over the past decade, ranging from 50,000 to 55,000 articles[44] per year between 1995 and 2008 (appendix table 5-42). The number of articles produced by scientists and engineers in the federal government and in industry was more than 15,000 in 1995 but slowly declined to range between 13,000 and 14,000 each through 2008 (figure 5-22). State and local government authorship, dominated by articles in the medical and biological sciences, remained constant across the decade. Between 1995 and 2008, scientists and engineers in the private nonprofit sector increased their output from about 15,000 to about 18,000.

Federally funded research and development centers (FFRDCs) are research institutions sponsored by federal agencies and administered by universities, industry, or other nonprofit institutions. FFRDCs have specialized research agendas closely related to the mission of the sponsoring agency and may house large and unique research

Figure 5-22
S&E article output of U.S. nonacademic sectors: 1996–2008



FFRDC = federally funded research and development center

NOTES: Article counts from set of journals covered by Science Citation Index (SCI) and Social Sciences Citation Index (SSCI). Articles classified by year they entered database, rather than year of publication, and assigned to sector on basis of institutional address(es) listed on article. Articles on fractional-count basis, i.e., for articles with collaborating institutions from multiple sectors, each sector receives fractional credit on basis of proportion of its participating institutions. Joint and unknown sectors omitted.

SOURCES: Thomson Reuters, SCI and SSCI, http://www.thomsonreuters.com/products_services/science/; The Patent Board™; and National Science Foundation, Division of Science Resources Statistics. See appendix table 5-42.

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instruments not otherwise available in other research venues. Although authors at FFRDCs published articles in all of the broad S&E fields considered in this chapter, articles in physics, chemistry, and engineering together represented 69% of publication by this sector in 2008, reflecting its specialized research programs. Physics articles accounted for 39% of the FFRDC total (9% of the total for all sectors); engineering articles for 15% (7% of the total for all sectors); and chemistry articles for 16% (8% of the total for all sectors (appendix table 5-42).

The 16 FFRDCs sponsored by the Department of Energy dominated S&E publishing by this sector. Across all fields of S&E, DOE-sponsored labs accounted for 83% of the total for the sector in 2005 (NSB 2008). Scientists and engineers at DOE-sponsored FFRDCs published 96% of the sector's articles in chemistry, 95% in physics, and 90% in engineering (see "S&E Articles From Federally Funded Research and Development Centers," NSB 2008, p 5-47). Nine other federal agencies, including the Departments of Defense, Energy, Health and Human Services, Homeland Security, Transportation, and Treasury; the National Aeronautics and Space Administration; the Nuclear Regulatory Commission; and National Science Foundation also sponsor another 23 FFRDCs (NSF/SRS 2009a).

In contrast, articles published by authors in the private nonprofit sector are primarily in the medical sciences (55% of the sector's articles in 2008) and biological sciences (25%) (appendix table 5-42). Federal government authors show a similar pattern, with 30% in the biological sciences and 27% in the medical sciences.

Trends in Sector Coauthorship

This section considers coauthorship data as an indicator of collaboration at the sectoral level between U.S. institutional authors and between U.S. sectors and foreign institutions.[45] These data show that the growing integration of R&D activities, as measured by coauthorship, is occurring across the full range of R&D-performing institutions internationally as well as domestically.

Between 1998 and 2008, coauthorship within sectors increased for all U.S. sectors.[46] Coauthorship within academia rose from 38% in 1998 to 45% in 2008. FFRDC-FFRDC coauthorship increased 5 percentage points (table 5-21).

U.S. cross-sectoral coauthorships show a mixed pattern between 1998 and 2008. Coauthorship between FFRDCs and industry decreased. (Articles authored by industry physicists have been declining gradually across the period. Since a strong emphasis of FFRDC-authored articles is in physics (39%), it may be that fewer and fewer physicists are available in industry for potential coauthorship with physicists in FFRDCs.)[47] The largest gains in all sectors (6.8–9.8 percentage points) were with coauthors in academia, by far the largest sector with the largest pool of potential S&E coauthors. Cross-sector coauthorship with academic authors was higher in 2008 (54%–74%) than intrasector coauthorship within academia (45%), and cross-sector coauthorship with academia was higher in all sectors than any intrasector coauthorship (table 5-21).

Except for the decline in coauthorship between FFRDCs and industry, the indicators presented in this section hint at increasing integration between and among the different types of U.S. institutions that publish the results of R&D in the scientific and technical literature. Growth in coauthorship has been particularly strong between U.S. authors in academia and in all other sectors. Because of the predominance of the academic sector in S&E article publishing in the United States, academic scientists and engineers have been on the forefront of the integration of S&E research across institutions, both nationally and internationally.

International collaboration increased rapidly in the United States. International coauthorship rates rose by 7–10 percentage points between 1998 and 2008 (table 5-21). Authors at FFRDCs reached the highest rate of collaboration with foreign authors, at 42%, followed by industry and academia at 29% each. Astronomers in most U.S. sectors increased their rates of international coauthorship the most rapidly, and geoscientists, mathematicians, and physicists in most U.S. sectors also increased their collaboration with international colleagues at a higher-than-average pace (NSB 2008, 08-01A, p A5-66).

Trends in Citation of S&E Articles

Citations indicate influence. When scientists and engineers cite the published papers resulting from prior S&E research, they are formally crediting the influence of that research on their own work. Like the indicators of international coauthorship discussed above, cross-national citations are evidence that S&E research is increasingly international in scope. Between 1992 and 2008, international citations grew faster than total citations: 5.8% annually versus 4.6% (figure 5-23). By 2008, international citations were two-thirds of all citations.[48]

Two other trends accompanied the steady growth of international citations in the world's S&E literature: changing shares of total citations across countries and changing shares of highly cited S&E literature. These are discussed in the following sections.

Citation Trends in a Global Context

Shares of the world total of citations to S&E research articles have changed concurrently with shares of the world total of these articles. Appendix table 5-43 shows, for example, that between 1994–96 and 2004–06, the U.S. share of world S&E articles declined from 34% to 29% across all fields;[49] the U.S. share declined in every broad field, although the decline varied in size. Table 5-22 shows the parallel trends for the U.S. share of citations and indicates an even larger decline, from 47% to 38%.

China's share of both total world S&E articles and citations increased over the same period. However, in contrast to the global trend of increasing international citations, China's pattern has been different. Unlike the United States and other large article-producing countries, China's share of international citations *decreased* between 1998 and 2008, from

Table 5-21
U.S. article coauthorship, by sector, foreign coauthorship, and U.S. coauthor sector: 1998 and 2008
(Percent)

Year/sector	Foreign coauthor	U.S. coauthor sector: FFRDCs	Federal government	State/local government	Academic institutions	Industry	Private nonprofit
1998							
Federal government	19.7	3.2	17.4	2.0	54.4	9.0	8.5
Industry	19.7	3.3	9.6	1.4	44.8	14.1	8.9
Academic	19.6	2.6	7.8	1.4	37.7	6.0	8.6
FFRDCs	32.9	12.6	8.6	0.2	48.5	8.4	3.4
Private nonprofit	17.8	1.2	8.0	2.3	57.1	8.0	24.3
State/local government	10.9	0.5	13.9	13.5	64.2	8.8	16.2
2008							
Federal government	27.4	4.0	20.5	2.9	62.0	9.5	12.9
Industry	29.2	3.5	10.5	1.9	53.8	17.9	13.5
Academic	28.8	3.2	8.1	1.5	45.2	6.4	10.5
FFRDCs	41.6	17.6	9.7	0.2	58.3	7.6	5.0
Private nonprofit	27.6	1.6	10.3	2.7	63.9	9.7	28.8
State/local government	17.8	0.6	18.3	15.6	74.0	10.8	21.7
1998–2008 change (percentage points)							
Federal government	7.8	0.8	3.1	0.9	7.6	0.5	4.5
Industry	9.5	0.2	0.8	0.5	9.0	3.8	4.6
Academic	9.2	0.6	0.3	0.2	7.5	0.3	1.9
FFRDCs	8.7	5.0	1.1	*	9.8	-0.7	1.6
Private nonprofit	9.7	0.4	2.2	0.5	6.8	1.8	4.5
State/local government	6.9	0.1	4.4	2.1	9.8	2.1	5.5

* = rounds to zero

FFRDC = federally funded research and development center

NOTES: Article counts from set of journals covered by Science Citation Index (SCI) and Social Sciences Citation Index (SSCI). Articles classified by year they entered the database, rather than year of publication, and assigned to sector on basis of institutional address(es) listed on article. Articles on whole-count basis, i.e., each collaborating country or sector credited one count. Articles from joint or unknown sectors omitted. Detail may add to more than 100% because articles may have authors from more than two sectors.

SOURCES: Thomson Reuters, SCI and SSCI, http://thomsonreuters.com/products_services/science/; The Patent Board™; and National Science Foundation, Division of Science Resources Statistics, special tabulations.

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64% to 51%, suggesting that much of the use of China's expanding S&E article output—as indicated by citations to those articles—is occurring *within* China.

Trends in Highly Cited S&E Literature

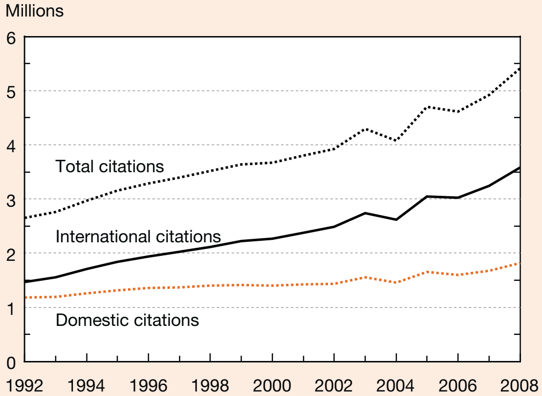
Another indicator of performance of a national or regional S&E system is the share of its articles that are highly cited. High citation rates can indicate that an article has a greater impact on subsequent research than articles with lower citation rates.

Appendix table 5-43 shows citation percentiles for 1998 and 2008 by field for the top five S&E article-producing countries/regions.[50] In that table, a country whose research influence was disproportionate to its output would have higher numbers of articles in higher citation percentiles, whereas a country whose influence was less than its output would suggest would have higher numbers of articles in lower citation percentiles. In other words, a country whose research is highly influential would have higher shares of articles in higher citation percentiles.

This is the case in every field for U.S. articles. In both 1998 and 2008, as displayed in appendix table 5-43, the U.S. share of articles in the 99th percentile was higher than its share in the 95th percentile, and these were higher than its share in the 90th percentile, and so forth, even while U.S. shares of all articles and all citations were decreasing. In 2008, U.S. articles represented 29% of the world total of 2 million articles in the cited period shown; the U.S. authored 52% of the rare 19,500 articles in the 99th percentile and 25% of the 1.2 million articles below the 50th percentile. This broad pattern was unchanged from the 1998 pattern.

Citations to the European Union's S&E articles displayed a different pattern: it had higher percentages of articles in the lower percentiles across all fields of S&E except in the agricultural sciences (appendix table 5-43). Figure 5-24 displays these relationships for all five countries/regions. Only U.S. publications display the preferred relationship of strongly higher proportions of articles in the higher percentiles of article citations; when cited, articles with authors from the European Union, China, Japan, and the Asia-8 are more

Figure 5-23
Total, domestic, and international citations: 1992–2008



NOTES: Citing and cited articles from set of journals covered by Science Citation Index (SCI) and Social Sciences Citation Index (SSCI). Articles classified by year they entered database, rather than year of publication. Citations on fractional-count basis, i.e., for citing and/or cited articles with collaborating institutions from multiple countries, each country receives fractional credit on basis of proportion of its participating institutions. Citation counts based on 3-year period with 2-year lag, e.g., citations for 2008 are references made in articles in 2008 data tape to articles in 2004–06 data tapes.

SOURCES: Thomson Reuters, SCI and SSCI, http://thomsonreuters.com/products_services/science/; The Patent Board™; and National Science Foundation, Division of Science Resources Statistics, special tabulations.

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often found in the lower citation percentiles. These data are summarized in appendix table 5-44. As the U.S. share of all articles produced declined between 1998 and 2008, its share of articles in the 99th percentile (i.e., the top 1%) of cited articles also declined, particularly in some fields. Shares in the top percentile increased for the European Union, China, Japan, and the Asia-8.

When citation rates are normalized by the share of world articles during the citation period to produce an index of highly cited articles, the influence of U.S. articles is seen to have changed little over the past 10 years. Between 1998 and 2008, the U.S. index of highly cited articles barely changed (from 1.83 to 1.78) (figure 5-25; appendix table 5-44) and remained well above the expected index value of 1. During the same period, the European Union increased its index from 0.73 to 0.89, and China, Japan, and the Asia-8 increased their index values but remained below their expected values. In other words, the United States had 78% more articles than expected in the 99th percentile of cited articles in 2008, and the European Union had 11% fewer than expected. China had 58% fewer articles in the 99th percentile than expected in 2008, and Japan 42% fewer.

The United States experienced notable gains on the index of highly cited articles in engineering and computer sciences (although with relatively low counts in the latter) and a decline in chemistry (appendix table 5-44). The European Union reached its expected value in chemistry, physics, and the agricultural sciences. China achieved an index value of 1 in engineering and mathematics. Japan did not achieve its expected value in any broad field.

Academic Patents, Licenses, Royalties, and Startups

Other indicators of academic R&D outputs reflect universities' efforts to capitalize on their intellectual property in the form of patents and associated activities. The majority

Table 5-22
S&E articles, citations, and international citations, by selected region/country: 1998 and 2008
(Percent)

Country/region	Share of world articles 1998	Share of world articles 2008	Share of world citations 1998	Share of world citations 2008	Share of world/country/economy citations that are international 1998	Share of world/country/economy citations that are international 2008
World	100.0	100.0	100.0	100.0	60.2	66.3
United States	34.0	28.9	46.9	38.3	46.9	51.8
EU	34.6	33.1	32.4	33.2	43.7	49.4
China	1.6	5.9	0.6	4.3	63.6	51.0
Japan	8.5	7.8	6.8	6.3	60.7	68.6
Asia-8	3.6	6.8	1.5	4.6	61.8	65.3

EU = European Union

NOTES: Article/citation counts from set of journals covered by Science Citation Index (SCI) and Social Sciences Citation Index (SSCI). Articles classified by year they entered database, rather than year of publication, and assigned to country/economy on basis of institutional address(es) listed on article. Articles on fractional-count basis, i.e., for articles with collaborating institutions from multiple countries/economies, each country/economy receives fractional credit on basis of proportion of its participating institutions. See appendix table 5-23 for countries/economies included in EU and Asia-8, which in this table are treated as single countries. Citation counts based on 3-year period with 2-year lag, e.g., citations for 1998 are references made in articles in 1998 data tape to articles in 1994–96 data tapes; data shown are for the 3 years in cited year window.

SOURCES: Thomson Reuters, SCI and SSCI, http://thomsonreuters.com/products_services/science/; The Patent Board™; and National Science Foundation, Division of Science Resources Statistics, special tabulations.

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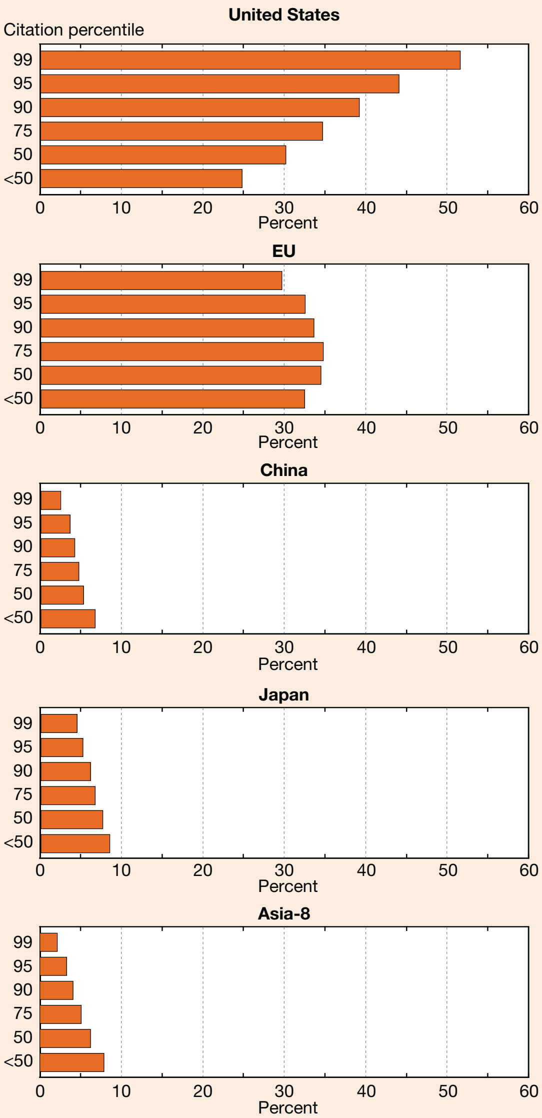
Figure 5-24
United States, EU, China, Japan, and Asia-8 share of cited papers, by citation percentile: 2008



EU = European Union

NOTES: Article/citation counts from set of journals covered by Science Citation Index (SCI) and Social Sciences Citation Index (SSCI). Articles classified by year they entered database, rather than year of publication, and assigned to country/economy on basis of institutional address(es) listed on article. Articles/citations on fractional-count basis, i.e., for articles with collaborating institutions from multiple countries/economies, each country/economy receives fractional credit on basis of proportion of its participating institutions. See appendix table 5-23 for countries/economies included in EU and Asia-8. Citation counts based on 3-year period with 2-year lag, e.g., citations for 2008 are references made in articles in 2008 data tape to articles in 2004–06 data tapes. Percentiles approximate because of method of counting citations and always higher than stated.

SOURCES: Thomson Reuters, SCI and SSCI, http://thomsonreuters.com/products_services/science/; The Patent Board™; and National Science Foundation, Division of Science Resources Statistics. See appendix table 5-43.

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of U.S. universities did not become actively involved in the management of their own intellectual property until late in the 20th century, although some were granted patents much earlier.[51] The Bayh-Dole Act of 1980 gave colleges and universities a common legal framework for claiming ownership of income streams from patented discoveries that resulted from their federally funded research. To facilitate the conversion of new knowledge produced in their laboratories to patent-protected public knowledge that can be potentially licensed by others or form the basis for a startup firm, more and more research institutions established technology management/transfer offices (AUTM 2009).

Efforts to encourage links between university-based research and commercial exploitation of the results of that research have been widely studied by researchers. Mowery (2002) notes the strong growth in funding by NIH and the predominance of biomedically related patenting by universities in the 1990s. Branstetter and Ogura (2005) identify a “bio-nexus” in patent-to-paper citations, and Owen-Smith and Powell (2003) explore the effects of an academic medical center as part of the “scientific capacity” of a research university. In a qualitative study of two research universities that would appear to have similar capacities, Owen-Smith and Powell (2001) examine the very different rates of invention disclosure of the two campuses. Stephan and colleagues (2007) found strong differences in patenting activity among university scientists by field of science; a strong relationship between publication activity and patenting by individual researchers; and patenting by university researchers in only a small proportion of the potential population.

The following sections discuss overall trends in university patenting and related indicators through 2007–08.

University Patenting Trends

U.S. Patent and Trademark Office (USPTO) data show that annual patent grants to universities and colleges ranged from 2,950 to 3,700 between 1998 and 2008 (appendix table 5-45). In 2008, just over 3,000 patents were awarded to colleges and universities in the United States.[52] (Data in the next section on invention disclosures and applications suggest that patent grants to academic institutions may increase in the coming years.)

The top 200 R&D-performing institutions, with 96% of the total patents granted to U.S. universities during the 1998–2008 period, dominate among universities and university systems receiving patent protection.[53] College and university patents as a percentage of U.S. nongovernmental patents fell from 5.2% in 1998 to 4.3% in 2008. Among the top R&D-performing institutions that received patents between 1998 and 2008, 19 accounted for more than 50% of all patents granted to these institutions (although these included a few multicampus systems, including the Universities of California and North Carolina).

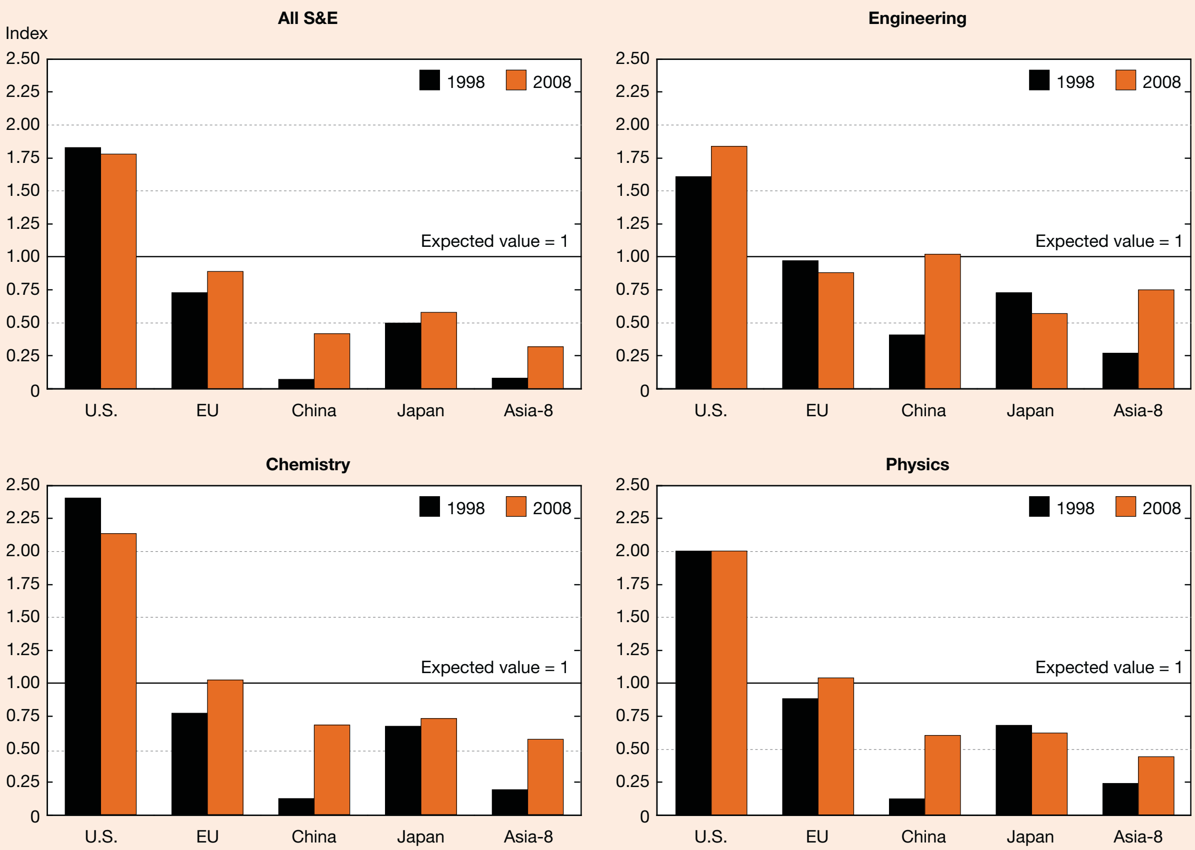
Between 1998 and 2008, three technology areas dominated U.S. university patenting: chemicals (19%), biotechnology (15%), and pharmaceuticals (14%) (appendix table 5-46). In numbers of patents, all three of these technology areas have declined from previous highs (figure 5-26). The next three highest technology areas over the period were semiconductors and electronics (6%), measurement and control equipment (5%), and computers and peripherals (5%), each accounting for about 200 patents in 2008 (appendix table 5-46).

Patent-Related Activities and Income

Data from the Association of University Technology Managers (AUTM) indicate continuing growth in a number of patent-related activities. Invention disclosures filed with university technology management offices describe prospective inventions and are submitted before a patent application is filed. These grew from 13,700 in 2003 to 17,700 in 2007 (notwithstanding a small decline in institutions responding to the AUTM survey over the same period) (appendix table 5-47). Likewise, new U.S. patent applications filed by AUTM respondents also increased, from 7,200 in 2003 to 10,900 in 2007. The AUTM survey respondents reported 348 startup companies formed in 2003 and 510 in 2007. The AUTM 2007 survey also found 3,148 cumulative, operational startup firms associated with U.S. university patenting and licensing activities (AUTM 2009).

Most royalties from licensing agreements accrue to relatively few patents and the universities that hold them, and many of the AUTM respondent offices report negative income. (Thursby and colleagues [2001] note that the objectives of university technology management offices include more than royalty income.) At the same time, large one-time payments to a university can affect the overall trend

Figure 5-25
Index of highly cited articles, by selected field and region/country: 1998 and 2008



EU = European Union

NOTES: Article/citation counts from set of journals covered by Science Citation Index (SCI) and Social Sciences Citation Index (SSCI). Articles/citations classified by year they entered database, rather than year of publication, and assigned to country/economy on basis of institutional address(es) listed on article. See appendix table 5-23 for countries/economies included in EU and Asia-8. Citation counts based on 3-year period with 2-year lag, e.g., citations for 2008 are references made in articles in 2008 data tape to articles in 2004–06 data tapes. Index of highly cited articles is country's share of world's top 1% cited articles divided by its share of world articles for the cited year window.

SOURCES: Thomson Reuters, SCI and SSCI, http://thomsonreuters.com/products_services/science/; The Patent Board™; and National Science Foundation, Division of Science Resources Statistics. See appendix table 5-44.

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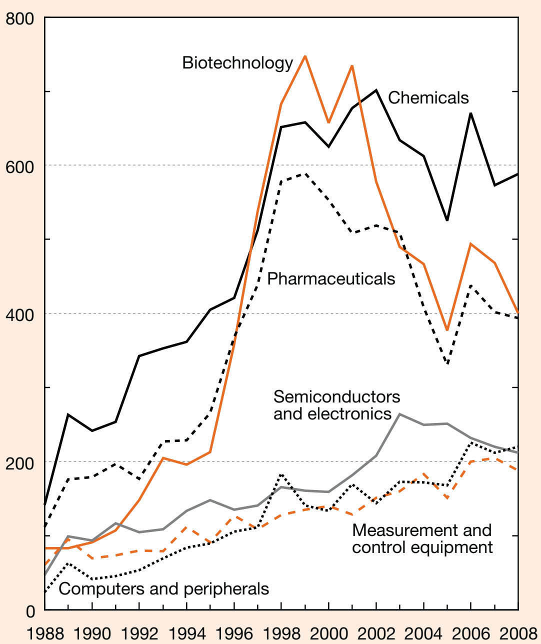
Figure 5-26
U.S. academic patents, by selected technology area: 1988–2008



NOTES: Data include institutions affiliated with academic institutions, such as university and alumni organizations, foundations, and university associations. The Patent Board™ technology areas constitute an application-oriented classification system that maps the thousands of International Patent Classes (IPCs) at the main group level into 1 of 30 technology areas. If a patent has more than one IPC, only primary IPC is considered in mapping.

SOURCES: The Patent Board™; and National Science Foundation, Division of Science Resources Statistics. See appendix table 5-46.

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in university licensing income. In 2007, the 161 institutions that responded to the AUTM survey reported a total of $1.9 billion in net royalties from their patent holdings (appendix table 5-47).

Between 2003 and 2007, the inventory of revenue-generating licenses and options across all AUTM respondent institutions increased from 9,000 to 12,500 (appendix table 5-47). New licenses and options executed grew over the period from about 3,900 in 2003 to 4,400 in 2007.

Patent-to-Literature Citations

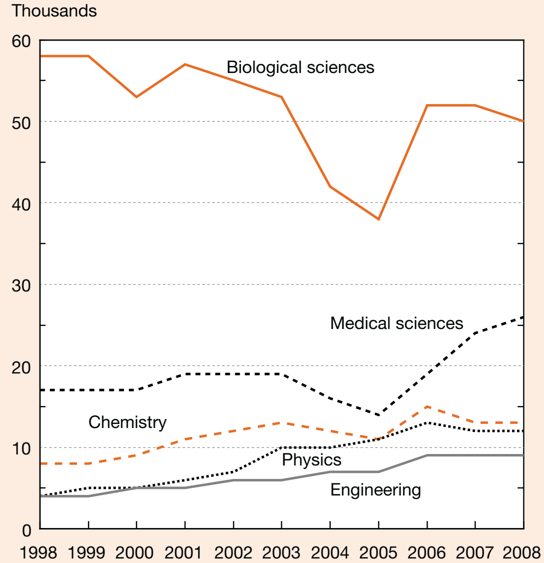
Citations to the S&E literature on the cover pages of issued patents are one indicator of the contribution of research to the development of practical innovation.[54] This indicator of science linkage to practical advance increased sharply in the late 1980's and early 1990's (Narin, Hamilton, and Olivastro 1997), due at least in part to developments in U.S. policy, industry growth and maturation, and court interpretation. At the same time, patenting activity by academic institutions was increasing rapidly, as were patent citations to S&E literature produced across all sectors (NSB 2008, pp. 5-49 to 5-54).

Between 1998 and 2008, growth on this indicator was much slower. Of utility patents awarded to both U.S. and foreign assignees, the number citing S&E articles (11% of total utility patents awarded in 2008) grew 1.4% annually over the 10-year period, compared with 0.7% annually for all utility patents (appendix table 5-48). Much of the growth in S&E citing patents was in patents awarded to non-U.S. assignees: these grew 3.1% annually.

Five broad S&E fields (the biological sciences, the medical sciences, chemistry, physics, and engineering) accounted for 97% of the total citations in these patents (appendix table 5-49 and figure 5-27). Citations to the biological sciences have decreased from their high of 58,000 in 1998 and 1999 but have more recently stabilized at around 50,000 per year. Citations to the medical sciences have increased since 2005 to about 26,000 in 2008.

The data discussed in the previous three paragraphs were heavily influenced by U.S. patents awarded to foreign assignees and references in those patents to non-U.S. S&E articles. Considering only citations to U.S. articles, overall growth in citations has been flat over the past 10 years (appendix table 5-48). Change in citations to articles authored in

Figure 5-27
Citations in U.S. patents to S&E articles, by selected article field: 1998–2008



NOTES: Citations are references to S&E articles in journals covered by Science Citation Index (SCI) and Social Sciences Citation Index (SSCI). Citation counts based on a 6-year window with 5-year lag, e.g., citations for 2002 are references in U.S. patents issued in 2002 to articles published in 1992–97.

SOURCES: U.S. Patent and Trademark Office; Thomson Reuters, SCI and SSCI, http://thomsonreuters.com/products_services/science/; The Patent Board™; and National Science Foundation, Division of Science Resources Statistics. See appendix table 5-49.

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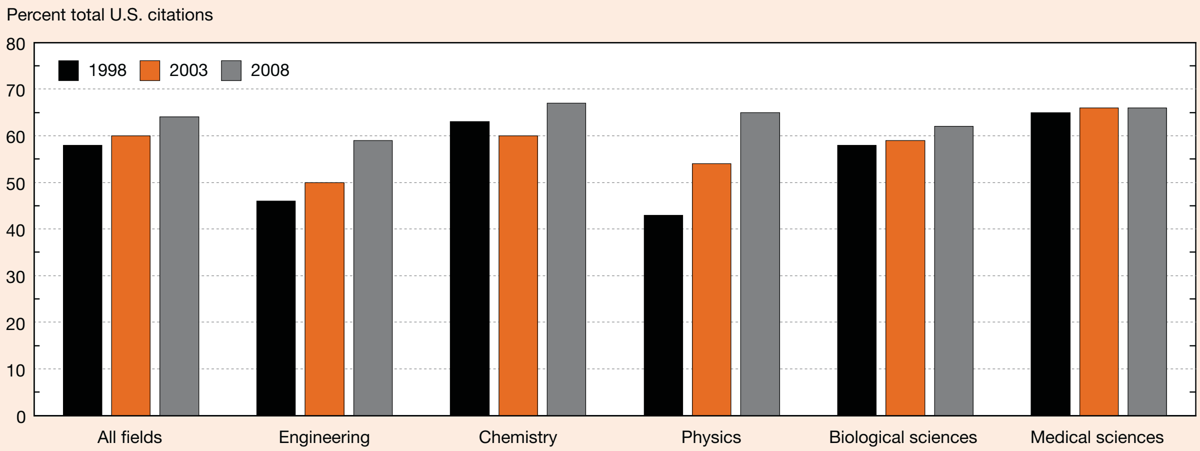
Figure 5-28
Academic share of U.S. patent citations to U.S. articles, by selected field: 1998, 2003, 2008



NOTES: Citations are references to U.S. S&E articles in journals covered by Science Citation Index (SCI) and Social Sciences Citation Index (SSCI). Citation counts based on a 6-year window with 5-year lag, e.g., citations for 2003 are references in U.S. patents issued in 2003 to articles published in 1993–98.

SOURCES: U.S. Patent and Trademark Office; Thomson Reuters, SCI and SSCI, http://thomsonreuters.com/products_services/science/; The Patent Board™; and National Science Foundation, Division of Science Resources Statistics. See appendix table 5-49.

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both the private nonprofit and government sectors has been negative over the period. Growth in citations to academic papers (0.9% annually) and to FFRDC papers (4.6% annually) shows that citations to papers in these two sectors have been replacing declining citations to articles in other sectors. Citations to academic articles account for most of this replacement, despite the slower rate of growth in these citations. Of total citations to U.S. articles in 2008, 64% were to academic articles, compared with 2% to FFRDC articles.

Figure 5-28 summarizes the increasing role of citations to U.S. academic articles in the science linkage to U.S. patents. Across all fields, academic articles made up 58% of total citations to U.S. articles in 1998 and 64% in 2008. Of the five broad fields of S&E that accounted for 97% of all patent citations to U.S. academic articles, increased shares of academic citations were notable in engineering (from 46% to 59%) and physics (from 43% to 65%). These increasing shares of patent citations to U.S. academic S&E articles are parallel to the increasing shares of academic S&E articles as compared with other sectors, as discussed above in the section “Trends in Output and Collaboration Among U.S. Sectors.”

Conclusion

U.S. universities and colleges continue to be important performers of U.S. R&D, and particularly basic research. Both the overall academic S&E doctoral workforce and the academic research workforce have continued to increase. Citation data indicate that U.S. scientific publications remain highly influential relative to those of other countries. While the United States continues to produce more S&E articles than any other country, its share of total world articles has declined due to high publication growth rates elsewhere, notably China.

Although funding for academic R&D has been increasing, a number of shifts in funding sources have occurred. After increasing between 2000 and 2004, the federal government’s share of funding for academic R&D decreased from 2005 through 2008. In addition, federal funding for academic R&D has either declined in constant dollars or remained flat since 2005. Industry support for academic R&D declined from 2002 to 2004 but rose again through 2008. The state and local government share of support for academic R&D has been generally declining since 1972, and the university share of support for academic R&D has been generally increasing.

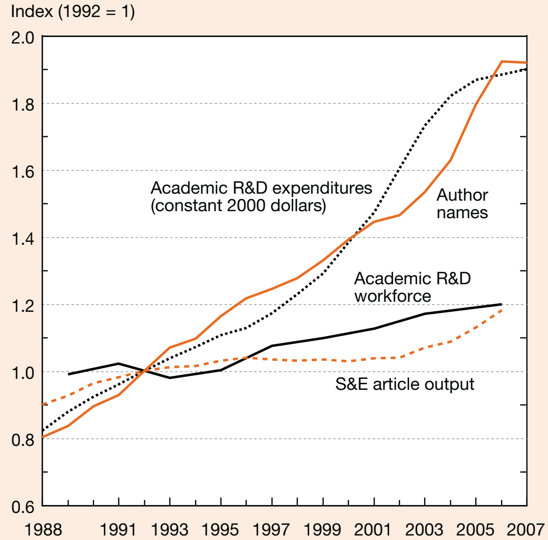
The structure and organization of academic R&D have also changed. (See sidebar “Publications and Resource Inputs.”) Research-performing colleges and universities continued to expand their stock of research space, particularly in the biological and medical sciences. The number of academic S&E doctoral researchers has grown over the past couple of decades, with the life sciences accounting for much of the trend. Life scientists accounted for more than a third of academic S&E doctoral researchers in 2006. Increasingly, these researchers are employed in postdoc or other nonfaculty positions. Particularly among life scientists, the number of new doctorate holders has increased greatly while the numbered

Publications and Resource Inputs

The publication of research results in peer-reviewed scientific journals is a key output of scientific research. In the early 1990s, the number of S&E articles published by U.S. academic scientists and engineers in the world's major peer-reviewed journals plateaued while resource inputs—funds and personnel—kept increasing (figure 5-B). With some variations, this trend occurred across different types of institutions and different fields, despite increases in research inputs such as funds and personnel (NSF/SRS 2007).

An examination of relationships among publications, resource inputs, and institutional characteristics in the top 200 academic R&D institutions found that, with the possible exception of S&E faculty and the number of S&E doctoral recipients, inflation-adjusted resources for publications have increased faster than the number of publications. From 1990 to 2001, resource inputs increased per publication, with about 29% more resources consumed per fractional count publication in 2001 than in 1990. This pattern of increasing inputs required to yield the same quantity of publication outputs occurred across the entire U.S. academic system. Possible reasons for the increasing inputs per article include a rise in the complexity of research required for publication; costs for faculty, postdocs, S&E doctoral recipients, and research materials and equipment that are increasing faster than the gross domestic product implicit price deflator; and increased communication costs for collaboration (NSF/SRS 2010, forthcoming). In figure 5-B, the steadily rising number of total author names on articles with at least one academic author is another indicator of the strong growth in research collaboration and article coauthorship noted elsewhere in this chapter.

Figure 5-B
U.S. academic S&E article output, S&E article author names, academic R&D expenditures, and academic R&D workforce: 1988–2007



NOTES: Data for academic workforce available for odd years and 2006; 1992 base year is average of 1991 and 1993 data. Article and author counts are two-year moving average from set of journals covered by Science Citation Index (SCI) and Social Sciences Citation Index (SSCI). Author counts include all authors on any article with one or more U.S. academic institutional addresses.

SOURCES: National Science Foundation, Division of Science Resources Statistics, Survey of Research and Development Expenditures at Universities and Colleges, FY 2007; Survey of Doctorate Recipients, special tabulations; Thomson Reuters, SCI and SSCI, http://thomsonreuters.com/products_services/science/; The Patent Board™; National Science Foundation, Division of Science Resources Statistics, special tabulations. See appendix tables 5-2 and 5-16.

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of tenured or tenure-track positions has remained relatively constant since the late 1980s.

Academic R&D is also becoming more international in a number of ways. U.S. academic scientists and engineers are collaborating extensively with colleagues in other countries: In 2008, 29% of journal articles with a U.S. academic author also had at least one coauthor from abroad. The intimate linkage between research and U.S. graduate education, regarded as a model by other countries, helps to bring large numbers of foreign students to the United States, many of whom stay after graduation. Academia has also been able to attract many talented foreign-born scientists and engineers into its workforce, with the percentage of foreign-born full-time doctoral S&E faculty in research institutions approaching half the total in some fields.

Notes

1. See appendix table 5-6 for the fields and subfields included in science and engineering in this section.

2. The academic R&D totals presented here exclude expenditures at federally funded research and development centers (FFRDCs) associated with universities. Those expenditures are tallied separately and are examined in greater detail in chapter 4. FFRDCs and other national laboratories (including federal intramural laboratories) also play an important role in academic research and education, providing research opportunities for both students and faculty at academic institutions and highly specialized shared research facilities.

3. For this discussion, the terms *universities and colleges, higher education*, and *academic institutions* are used interchangeably and include only those schools that grant a

bachelor's or higher degree in science or engineering and spend at least $150,000 for separately budgeted R&D in S&E.

4. For the definitions used in NSF surveys and a fuller discussion of these concepts, see chapter 4 sidebar, "Definitions of R&D."

5. The discussion of federal support for academic R&D includes both obligation data from the funding source (federal agencies) and expenditures data from the performer (universities and colleges).

6. The academic R&D reported here includes separately budgeted R&D and related recovered indirect costs as well as institutional estimates of unrecovered indirect costs associated with externally funded R&D projects, including mandatory and voluntary cost sharing.

7. This funding was required to be obligated by the end of FY 2009; however, the expenditures for these projects will span several years.

8. Performing and funding series may differ for many reasons. For a more detailed discussion of the differences between these two sources, see chapter 4 sidebar, "Tracking R&D: Gap Between Performer- and Source-Reported Expenditures."

9. Federal grants and contracts and awards from other sources that are passed through state and local governments to academic institutions are credited to the original provider of the funds.

10. This follows a standard of reporting that assigns funds to the entity that determines how they are to be used rather than to the one that necessarily disburses the funds.

11. The medical sciences include fields such as pharmacy, neuroscience, oncology, and pediatrics. The biological sciences include fields such as microbiology, genetics, epidemiology, and pathology. These distinctions may be blurred at times because boundaries between fields often are not well defined.

12. In this section of the chapter and the section "Doctoral Scientists and Engineers in Academia," the broad S&E fields refer to the computer sciences, environmental sciences (sometimes referred to as "earth, atmospheric, and ocean sciences"), life sciences, mathematical sciences, physical sciences, psychology, social sciences, other sciences (those not elsewhere classified), and engineering. The more disaggregated S&E fields are referred to as "subfields." The fourth section of the chapter, "Outputs of S&E Research: Articles and Patents," groups the broad fields and subfields slightly differently (see sidebar "Bibliometric Data and Terminology" and appendix table 5-24).

13. Data reported on non-S&E R&D expenditures are slightly lower-bound estimates for the national totals because NSF did not attempt to estimate for the 2.7% nonresponse rate on this item. Also, only institutions that conducted at least $150,000 of S&E R&D were surveyed. The activities of institutions that do not perform S&E R&D (but may conduct substantial amounts of non-S&E R&D) are not reflected here.

14. Data on non-S&E R&D expenditures have only been collected since FY 2003, and response rates for years prior to 2006 make trend data unreliable.

15. Another hypothesis is that some of the difference may be due to many public universities not having the incentive to negotiate full recovery of indirect costs of research because such funds are frequently returned to the state treasury rather than the institution.

16. Amounts reported as passed through to higher education subrecipients do not precisely equal amounts reported as received by those subrecipients due to differences in timing and in the item response rates for these two survey questions each year.

17. Because of rising capitalization thresholds, the dollar threshold for inclusion in the equipment category has likely changed over time. Generally, university equipment costing less than $5,000 would be classified under the cost category of "supplies."

18. The "bricks and mortar" section of the Survey of Science and Engineering Research Facilities asks institutions to report their research space only. The reported figures therefore do not include space used for other purposes such as instruction or administration. In the cyberinfrastructure section of the survey, however, respondents are asked to identify all of their cyberinfrastructure resources, regardless of whether these resources were used for research or other functions.

19. Research-performing academic institutions are defined as colleges and universities that grant degrees in science or engineering and expend at least $1 million in R&D funds. Each institution's R&D expenditures are determined through the NSF Survey of Research and Development Expenditures at Universities and Colleges.

20. Research space here is defined as the space used for sponsored R&D activities at academic institutions that is separately budgeted and accounted for. Research space is measured in net assignable square feet (NASF), the sum of all areas on all floors of a building assigned to, or available to be assigned to, an occupant for a specific use, such as research or instruction. NASF is measured from the inside faces of walls. Multipurpose space that is at least partially used for research is prorated to reflect the proportion of time and use devoted to research.

21. The S&E fields used in the NSF Survey of Science and Engineering Research Facilities are based on the National Center for Education Statistics (NCES) Classification of Instructional Programs (CIP). NCES updates CIP every 10 years. The S&E fields used in the FY 2007 Survey of Science and Engineering Research Facilities reflect the NCES 2000 CIP update. For a comparison of the subfields in the FY 2005 and FY 2007 surveys, see the S&E Research Facilities: FY 2007 detailed statistical tables.

22. Institutional funds may include operating funds, endowments, tax-exempt bonds and other debt financing, indirect costs recovered from federal grants/contracts, and private donations.

23. The United States is unlike many other countries in the fraction of doctorate holders who are employed in academia. A comparison of 1990–2006 doctorate recipients in 14 countries for which data are available found that in most of these countries, more than half of doctorate holders were employed in academia, compared with 47% for the United States. Only the United States, Austria, and Belgium had substantial fractions employed in the business sector, and the United States had one of the smallest fractions employed in government (OECD 2009).

24. Psychology (also called a behavioral science) is discussed and broken out separately in tables from the social sciences because trends over time and characteristics of doctorate holders in psychology and social sciences differ.

25. The inclusion or exclusion of those on temporary and permanent visas has little impact on the analysis. Data on Pacific Islanders were not collected separately from Asians before 2001. From 1975 to 1999, the Asian category includes Pacific Islanders, but from 2001 to 2006 it does not. In 2006, approximately 200 Pacific Islander doctoral S&E researchers were employed in academia. If combined with Asians, they would constitute less than 1% of the combined category.

26. The Carnegie classification used in that report was the 1994 version.

27. The switch to the American Community Survey as the sampling frame for the National Survey of College Graduates in 2010 and beyond may improve estimates of non-U.S.-trained doctorate holders in future years.

28. Among all S&E doctorate holders employed in academia, this is the case both in fields in which postdocs are prevalent (such as physical sciences and life sciences) and fields in which postdocs are less prevalent (such as computer sciences and mathematics).

29. Interpretation of the data on federal support of academic researchers is complicated by a technical difficulty. Between 1993 and 1997, respondents to the Survey of Doctorate Recipients were asked whether work performed during the week of April 15 was supported by the federal government; in most other survey years, the reference was to the entire preceding year, and in 1985, it was to 1 month. However, the volume of academic research activity is not uniform over the entire academic year. A 1-week (or 1-month) reference period seriously understates the number of researchers supported at some time during an entire year. Thus, the numbers for 1985 and 1993–97 cannot be compared directly with results for the earlier years or with those from the 1999 through 2006 surveys, which again used an entire reference year.

The discussion in this edition of *Indicators* generally compares data for 2006 with data for 1991. All calculations express the proportion of those with federal support relative to the number responding to this question. The reader is cautioned that, given the nature of these data, the trends discussed are broadly suggestive rather than definitive. The reader also is reminded that the trends in the proportion of all academic researchers supported by federal funds occurred against a background of rising overall numbers of academic researchers.

30. Respondents were asked to indicate whether they “Work with an immediate work group or team?”; “Work with others in the same organization (company, university, agency, etc.), but not the same group or team?”; “Work with individuals in other organizations in the U.S.?”; and “Work with individuals located in other countries?”

31. Publication traditions in broad S&E fields differ somewhat. For example, computer scientists often publish their findings in conference proceedings, and social scientists often write books as well as publish in journals. Proceedings and books are poorly covered in the data currently used in this chapter.

32. The U.S. sector identification in this chapter is quite precise; to date, sector identification has not been possible for other countries.

33. European Union data include all member states as of 2007 (see appendix table 5-23 for a list of member countries).

34. The Asia-8 includes India, Indonesia, Malaysia, Philippines, Singapore, South Korea, Thailand, and Taiwan.

35. For example, Vatican City is not strictly a country; the Union of Soviet Socialist Republics (USSR) and Hong Kong are contained in the data in earlier years, but the USSR no longer exists and Hong Kong data are now reported as part of China. See appendix table 5-23 for a list of the countries represented in the data.

36. Distributions of data in which a small percentage of cases accounts for a significant amount of the total value across all cases belong to a group of statistical distributions collectively referred to as *power law distributions* (Adamic 2000). Other phenomena with such distributions include, e.g., earthquakes (among a large number of earthquakes only a few have great power) and Internet traffic (visits to a relatively small number of sites account for a very large proportion of visits to all sites).

37. For example, Montenegro appeared in the data in 2006 for the first time as an independent country; the tiny Pacific island nation of Niue appeared in 2007 for the first time because a coauthor from that country appeared in the data.

38. See also NSB 2008, table 5-21, for detail on field level ranks and changes in rank since 1995.

39. Coauthorship data are a broad, though limited indicator of collaboration among scientists. Previous editions of *Indicators* discussed possible underlying drivers for increased collaboration, including scientific advantages of knowledge- and instrument-sharing, decreasing costs of travel and communication, national policies, and so forth (NSB 2006). Katz and Martin (1997), Bordons and Gómez (2000), and Laudel (2002) analyze limitations of coauthorship as an indicator of research collaboration. Other researchers have continued using these data (Adams et al. 2005; Gómez, Fernández, and Sebastián 1999; Lundberg et al. 2006; Wuchty, Jones, and Uzzi 2007; Zitt, Bassecoulard, and Okubo 2000).

40. The reader is reminded that the data on which these indicators are based give the nationality of the institutional addresses listed on the article. Authors themselves are not associated with a particular institution and may be of any nationality. Therefore the discussion in this section is based on the nationality of institutions, not authors, and makes no distinction between nationality of institutions and nationality of authors.

41. The coauthorship data discussed in this paragraph are restricted to coauthorship across the regions/countries identified in table 5-17; that is, collaboration between or among countries of the European Union, e.g., is ignored. *Intraregional* coauthorship is discussed in the following sections.

42. Readers are reminded that the *number* of coauthored articles between any pair of countries is the same; each country is counted once per article in these data. However, countries other than the pairs discussed here may also appear on the article.

43. Finland is included here as one of the Scandinavian countries; Iceland is not.

44. Article counts in this section are based on the year in which the article appeared in the database, not on the year of publication, and therefore are not the same counts as in the earlier discussion of total world article output.

45. Identification of the sector of the non-U.S. institution is not possible with the current data set.

46. Readers are reminded that coauthors from different departments in an institution are coded as different institutions.

47. Referring to the declining share of industry's basic research articles in physics, the National Science Board (NSB) noted, "Most of this decline is accounted for by widespread restructuring of a few large corporations during this period, including closure, downsizing, or reorientation of large central research laboratories. Increased globalization, intensified competition, and commercial priorities may have contributed to the decline in publishing by companies and their researchers" (NSB 2008, p 6-36).

48. This chapter uses the convention of a 3-year citation window with a 2-year lag, e.g., 2008 citation rates are from references in articles contained in the tape for 2008 to articles contained in the 2004, 2005, and 2006 tapes of the Thomson Reuters Science Citation Index and Social Sciences Citation Index databases. Analysis of the citation data shows that, in general, the 2-year citing lag captures the 3 peak citation years for most fields, with the following exceptions: in astronomy and physics, the peak citation years are generally captured with a 1-year lag, and in computer sciences, psychology, and the social sciences with a 3-year lag.

49. The reader is reminded that articles in this section are counted by the year they entered the database, not by year of publication. Therefore article counts, and percentages based on them, are different from the data presented earlier in this section.

50. Percentiles are specified percentages below which falls the remainder of the articles, e.g., the 99th percentile identifies the number of citations 99% of the articles failed to receive. For example, across all fields of science, 99% of articles from 2004 to 2006 failed to receive at least 22 citations in 2008. Matching numbers of citations with a citation percentile is not precise because all articles with a specified number of citations must be counted the same. Therefore, the citation percentiles discussed in this section and used in appendix tables 5-43 and 5-44 have all been counted conservatively, and the identified percentile is in every case higher than specified, i.e., the 99th percentile is always greater than 99%, the 95th percentile is always greater than 95%, and so forth. Actual citations/percentiles per field vary widely because counts were cut off to remain in the identified percentile. For example, using this method of counting, the 75th percentile for engineering contained articles with three to four citations in 2004 through 2006, whereas the 75th percentile for the biological sciences contained articles with five to eight citations.

51. For an overview of these developments in the 20th century, see Mowery (2002).

52. It is unclear whether the recent downturn in patents granted to universities/colleges is a result of changes in USPTO processing. For example, in its Performance and Accountability Report Fiscal Year 2008, USPTO reported an increase in average processing time ("patent average total pendency") from 29.1 months in 2005 to 32.2 months in 2008 (USPTO 2008).

53. The institutions listed in appendix table 5-45 are slightly different from those listed in past volumes, and data for individual institutions may be different. In appendix table 5-46, an institution is credited with a patent even if it is not the first assignee, and therefore, some patents may be double counted. Several university systems are counted as one institution, and medical schools may be counted with their home institution. Universities also vary in how they assign patents, e.g., to boards of regents, individual campuses, or entities with or without affiliation with the university.

54. Patent-based data must be interpreted with caution. Year-to-year changes in the data may reflect changes in USPTO processing times (so-called patent pendency rates). Likewise, industries and companies have different tactics and strategies for pursuing patents, and these may also change over time.

Patent citations to S&E research discussed in this section are limited to the citations found on the cover pages of successful patent applications. These citations are entered by the patent examiner, and may or may not reflect citations given by the applicant in the body of the application. Patent cover pages also contain references to scientific and technical materials not contained in the article data used in this chapter, e.g., other patents, conference proceedings, industry standards, etc. Analyses of the data referred to in this section found that nonjournal references on patent cover pages accounted for 19% of total references in 2008. The journals/articles in the SCI/SSCI database used in this chapter—a set of relatively high-impact journals—accounted for 83% of the journal references, or 67% of the total science references, on the patent covers.

Glossary

Academic doctoral S&E workforce: Includes those with a U.S. doctorate in an S&E field employed in 2- or 4-year colleges or universities in the following positions: full and associate professors (referred to as *senior faculty*); assistant professors and instructors (referred to as *junior faculty*); postdocs; other full-time positions such as lecturers, adjunct faculty, research associates, and administrators; and part-time positions of all kinds.

Academic institution: In the "Financial Resources for Academic R&D" section of this chapter, an academic institution is generally defined as an institution that grants a bachelors' or higher degree in science or engineering and that has spent at least $150,000 for separately budgeted R&D in S&E within the fiscal year being measured. Elsewhere in the chapter, this term encompasses any accredited institution of higher education.

Underrepresented minority: Demographic category including blacks, Hispanics, and American Indians/Alaska Natives, groups considered to be underrepresented in academic institutions.

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